THOMASON

CIVIL ENGINEERING COLLEGE

MANUALS,

COMPILED BY THE COLLEGE STAFF.

[NEW SERIES.]

No. X.

IRRIGATION WORKS.

SECOND EDITION.

EDITED BY LIEUT.-COL. J. G. MEDLEY, R.E.

ROORKEE:
PRINTED AT THE THOMASON CIVIL ENGINEERING COLLEGE PRESS.
1873.

JAMES JOHNSTON, SUPERINTENDENT.

PREFACE TO SECOND EDITION.

THIS Edition of the "Irrigation Works" Manual is a reprint of the Section No. X. on this subject, in the 2nd Edition of the Roorkee Treatise on Civil Engineering. In the Preface to that work, Col. Medley wrote thus:—

"The Section on IRRIGATION WORKS has been much enlarged, many additional examples given, and a few valuable notes added by the late Col. Anderson, R.E.: I am also greatly indebted to Captain Scott Moncrieff, R.E., Superintending Engineer, Ganges Canal, for information and corrections supplied in the Chapters relating to Canal Management."

A. M. L.

10*th February*, 1873.

PREFACE TO FIRST EDITION.

THE want of a text-book has been long felt in teaching the principles of Irrigation Works to the Students of this College, and the object of this Manual is chiefly to supply that want; but it is hoped that it will also be found of service to young Engineers in the Irrigation Department generally.

The books chiefly consulted in the preparation of this treatise have been the following:—

Sir P. Cautley's Report on the Ganges Canal.

" " Eastern Jumna Canal.

Capt. Dyas' Report and Revised Estimate of the Baree Doab Canal.

Capt. Crofton's Report on the proposed Sutlej Canal.

Col. Dicken's Report on the proposed Soane Canal.

Col. Baird Smith's Report on Italian Irrigation.

" " Madras Irrigation.

" Instructions to Canal Officers.

Capt. Morton's Treatise on Rajbuhas.

Capt. Crofton has kindly aided me by revising most of the proof-sheets, and by the addition of many valuable notes and corrections. Lieut. Moncrieff, R.E., has also assisted me in some of the calculations, and to Mr. Login, I am indebted for *Plate* I. of the Series. I need hardly draw attention to Major Brownlow's valuable Memorandum on Canal management, which will be found in the Appendix.

This treatise, like those on Roads and Bridges, lately published, was originally written in the form of Lectures, which were delivered at the Calcutta C. E. College in 1862, and in the Thomason College in 1863.

J. G. M.

August 15*th*, 1863.

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PREFACE

TO

CLASSIFIED EDITION

OF

PROFESSIONAL PAPERS ON INDIAN ENGINEERING.

[FIRST SERIES.]

The "First Series" of Professional Papers on Indian Engineering was brought to a close at the end of 1870. This publication had been ably edited for seven years by Colonel J. G. Medley, R.E., while he held the post of Principal of the Thomason C. E. College at Roorkee, and when he left India, the material collected and published by him as records of Indian Engineering amounted to 294 separate papers forming seven Volumes, and published at a price of Rs. 120. As many an Engineer who had not been among the original Subscribers to this serial publication, while unwilling to expend so large a sum on the purchase of the complete Series, might be glad to possess himself, at a more moderate cost, of such papers as bear directly upon the branch of Engineering in which he is especially engaged or interested: it has been decided to publish a small Edition of the "First Series" of "Professional Papers on Indian Engineering" in a classified form: arranging methodically as ten separate Volumes, the original papers or articles which were before (necessarily) published in no systematized form in the seven annual Volumes.

The subject, contents, and price of each Volume (or Section) of this Edition are as follows:—

	RS.	A.	P.
Section A.—Architecture and Building, ...	25	0	0
„ B.—Bridges, ...	16	0	0
„ C.—Roads and Railways,... ...	20	0	0
„ D.—Canals, Tanks and Irrigation,	20	0	0

THOMASON COLLEGE PRESS PUBLICATIONS.

		RS.	A.	P.
Section E.—River and River Works,	...	15	0	0
„ F.—Light-houses and Harbour Works,		6	0	0
„ G.—Water Supply and Drainage,	...	8	0	0
„ H.—Surveying, ...	...	12	0	0
„ I.—Military Engineering, ...	...	7	0	0
„ K.—Engineering Mathematics,	...	12	8	0

In this form the Engineer whose duties and tastes incline him to the study of Hydraulic Engineering can purchase all the papers in this series relating to *irrigation* in a complete and compendious form and at a moderate cost, without having to pay for articles on general building, or railways, or on other subjects in which he has no immediate interest. And similarly the officer employed on Barracks, Churches or other Public Buildings will probably content himself with the purchase of Section A alone, and will find all the papers bearing on this branch of Engineering, collected into one book, instead of scattered through seven volumes.

Copies of the First Series are still available in their original form.

	RS.	A.	P.		RS.	A.	P.
Vol. I. 2nd Edition,	12	0	0	Vol. V. 1st Edition,	18	0	0
„ II. „ (*in the Press*),	12	0	0	„ VI. „ „	18	0	0
„ III. 1st Edition,	18	0	0	„ VII. „ „	14	0	0
„ IV. „ „	18	0	0				

"A Second Series" has been commenced, and a number is published once in every three months. The first Volume, costing Rs. 21, will consist of six Nos., of which five have been already issued.

A. M. L.

IRRIGATION WORKS.

1. IRRIGATION is either Natural or Artificial. The former depends upon Rain, upon Wells, and upon the flooding of Rivers. The latter comprises two important classes of Works—Canals and Tanks—which will be treated of in their proper order.

With Rain Irrigation the Engineer has nothing to do except under the head of Drainage of Lands; a separate branch of Engineering which will not be treated of under this Section.

CHAPTER I.

WELL IRRIGATION.

2. With Well Irrigation the Engineer's chief business is to devise machinery for raising the water, which more properly belongs to the subject of Mechanical Engineering.

It may be useful however to show the cost of raising water by the various methods generally used in India,—if only to show the utility of introducing Canal or Tank Irrigation even in districts already irrigated by wells. Some idea may be formed of this when it is considered that the Ganges Canal alone is calculated to perform the work of 300,000 men and 1,200,000 bullocks, besides increasing the produce of well-irrigated crops by 50 per cent.

The three modes in general use for raising water from wells in India are the *Paecottah* for Bengal (and Southern India, when tanks do not exist), the *Môt* or *Churus* for the N. W. Provinces, Rajpootana, &c., and the *Persian Wheel* for the Punjab.

3. The *Paecottah* or *Latha*, is a lever with a bucket at one end attached by a rope, and a counterpoise at the other end. It is worked by two men, who will work at it from 6 to 8 hours daily and, it is

said,* they will in 6 hours raise 2,500 cubic feet of water from a depth of 20 feet. Another calculation,† however, gives 1,357 lbs. of water as drawn from a depth of 36 feet in half an hour, equivalent to 260 cubic feet in 6 hours; and this result, making allowance for the difference of lift, differs so widely from the first, that neither can safely be taken as a guide. When the depth is moderate (according to the same authority) three men with two lathas will water from one-third to two-thirds of an acre daily.

The walking beam is another form of the paecottah, by which one man, it is said,‡ can raise 400 cubic feet in a working day of 8 hours from a depth of 11 feet, which agrees better with the second of the two calculations given above.

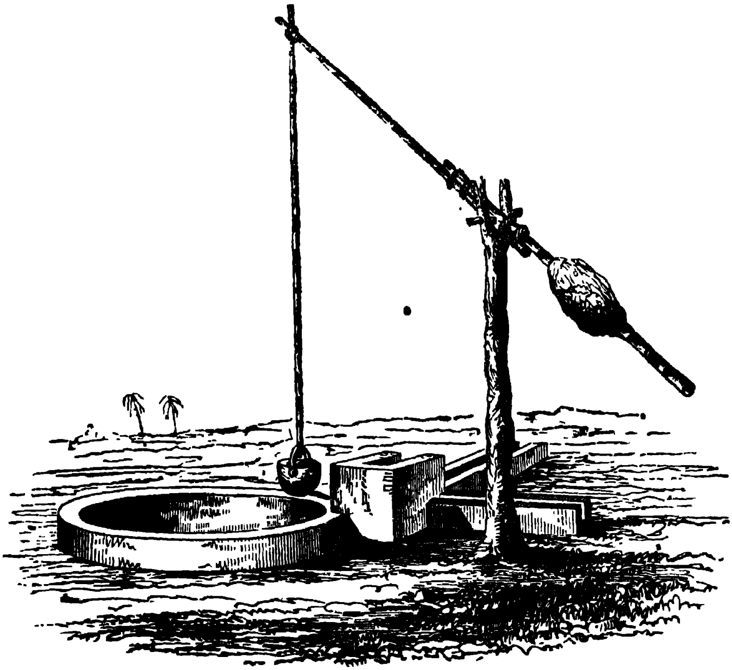
4. The *Môt* or *Churus* used in the N. W. Provinces and elsewhere, consists of a leathern bag made from a whole ox-hide, which when filled, is raised from the well by 2 bullocks walking down a slope, and emptied by an attendant on arrival at the top. Sometimes it is fitted with a leathern pipe at the bottom of the bag, which, by means of a string, can be worked by the bullock driver from the end of the slope so as to empty the bag and dispense with the services of the attendant.

Sometimes also, by means of a drum, two môts are worked, one being raised while the other is lowered.

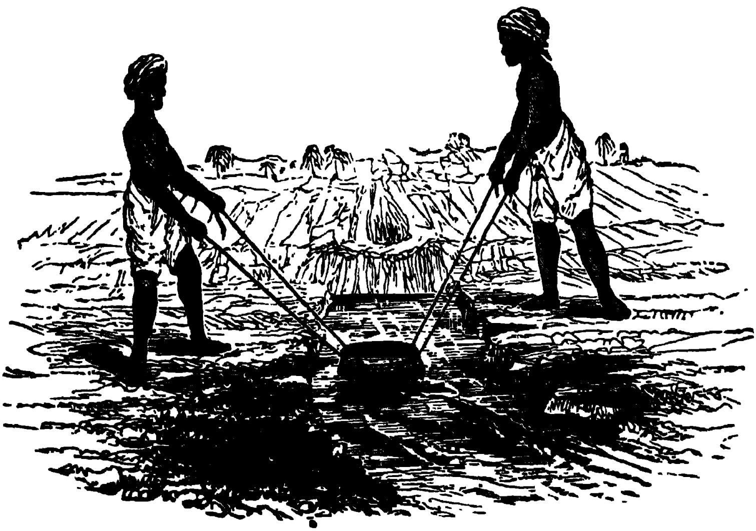
"Three men and two oxen work a môt from morning until evening, with a refreshment of only about of ¾ths of an hour. In a well 33 feet from the surface to the water, a môt in half an hour drew 7,210 lbs.; but such superiority over the lathas is not admitted by the natives, who contend that three lathas wrought by four men are equal to a môt wrought by three men and two oxen. This, however, I have no doubt, is a mistake, unless when the water is very near the surface."§

|| "From personal measurement we deduce that a leather bag as used in the North-West Provinces, contains 4·5 cubic feet, and that two pair of bullocks, relieving each other in the manner above described, will raise this bag full of water to the surface of the ground forty times in an hour. Supposing the bullocks work ten hours a day, and taking ninety days as the working season, we have the following result:—$4{\cdot}5 \times 40 \times 10 \times 90 = 162{,}000$ cubic feet. One acre = 43,560 super-

* Madras Engineer Papers, Vol. II.
† Gleanings in Science, Vol. II.
‡ Gleanings in Science, Vol. I.
§ Gleanings of Science.
|| Calcutta Engineer's Journal.

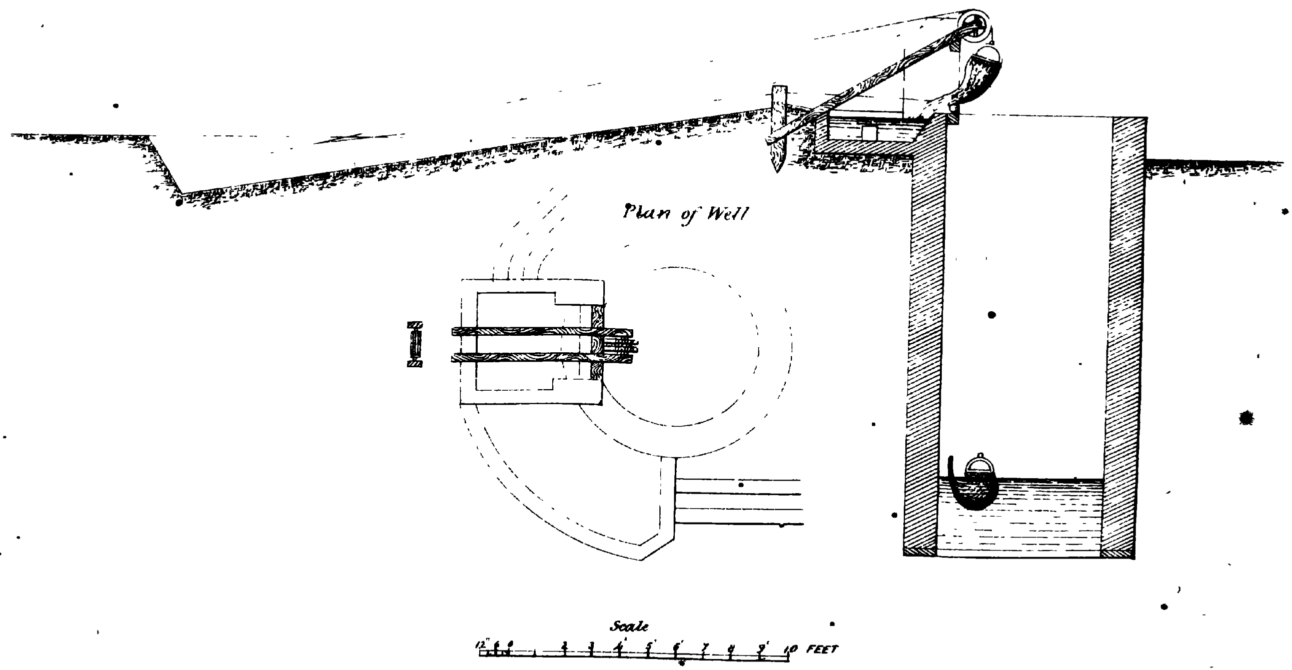


THE PAECOTTAH.



BALING.

WELL IRRIGATION.
THE SINGLE MÔT.



ficial feet. $\frac{162000}{43560} = 3.72$ acres, covered 1 foot deep with water, as the result of the labor of two pairs of bullocks and three men, working ten hours a day for ninety days. From the above description of the well system of Irrigation, it will be seen that it is very expensive, and can only be of very restricted application.

" Besides the objection of expense in working, this system is quite impracticable in large tracts of the Doab, as the sandy nature of the sub-soil entails the necessity of masonry wells, and it is quite plain that such a well, costing at least Rs. 500 to even every 20 acres, is entirely out of the question. The ordinary well is simply a round hole, lined, for a few feet of its height from the bottom, with a wooden or plaited brush-wood casing."

5. The following Notes on this subject, from Colonel Dickens' Report on the Soane Canals (published in) will also be found useful :—

The irrigation of the spring crop is for the most part effected by drawing water from wells by means of bullocks and the leather bag called a *môt*. In some places, where the water is near the surface, the weighted lever (*lāt*) is used, but it is a more expensive mode of raising water than by the bullocks and *môt*, except where the depth of the wells is very small.

The wells are not deep, reaching generally from 18 to 28 feet below the surface :* on the average perhaps 22 feet. But the supply of water is in most parts of the district scanty, and little more than a foot remains in the wells while the *môt* is in use.

To irrigate the crop, the water is run through the fields in channels, whence it is sprinkled over the crop with wooden scoops. This mode of irrigation is very inferior to that practised in other parts of India (and for opium in Shahabad) of allowing the water to submerge the whole field, plot by plot.

With wells of the average depth, the irrigation requires two pairs of bullocks (to work and rest by turns) and two men at the well, besides a woman or boy in the field to form the channels and sprinkle the water. On an average, one *môt* will water about $\frac{4}{5}$ths of a beegah ($\frac{4}{8}$ths of an acre†) in a day. A laborer who has received an advance of money from his employer gets $2\frac{1}{2}$ or 3 seers (5 or 6 lbs.) of one of the cheapest kinds of grain as his daily wages, value about 3 pice, or 20 or 21 *gundas* (or fours) to the rupee (that is 80 to 84 to the rupee, 40 to 42 pice to a shilling). A laborer not in debt is allowed 4 seers of grain, value about 4 of the pice current in the district, or $\frac{5}{6}$ths of an anna of the Company's coinage ($1\frac{1}{4}$ penny) as his day's wages. I was not able to form a satisfactory direct estimate of the cost of

* This refers to the Shahabad and other districts in Behar. In the Punjab the distance to the surface of the water from the ground is often 40 or 50 feet. The length of the time then consumed in raising the Môt makes it inferior to the Persian Wheel, hereafter described, which gives a continuous stream.—[ED].

† The beegah of 3,025 square yards is used in Shahabad.

keeping up the bullocks and their gear with the *môt*, but I found the established rate of hire for the two pairs of bullocks with gear and môt is 4 annas (6 pence) a day. The cost to the proprietors would, I suppose, be something less. I therefore set down the cost of one day's irrigation from wells, as follows :—

	RS.	A.	P.	£	s.	d.
2 men, ...	0	1	6	0	0	2¼
1 woman or boy, omitted, being also required for canal irrigation, ...	0	0	0	0	0	0
Bullocks and *môt*, ...	0	3	6	0	0	5¼
One day, or to water ⅗ths of a beegah, ⅜ths acre,	0	5	0	0	0	7½
To water a beegah once, therefore, costs, ...			Rs.	0	8	4
And an acre, ...			£	0	1	8

The greater part of the spring crop is watered only once or twice in the season, but some of it three times, particularly wheat. Wheat in some few places is watered four times. Where the irrigation was industriously applied I generally found the rule to be to water barley twice and wheat three times. The excuse for not irrigating more in places where the above was not acted up to, was more frequently want of *time* than want of *water*. I am inclined to think the real cause is often indolence rather than scarcity of labor. But for either case the supply of canal irrigation affords a remedy, as it saves both laborers and trouble.

6. Excepting in the rich land near the Ganges and a few other favored spots, the unirrigated crops of wheat and barley are very scanty, and are said to produce only from 2 to 6 maunds of grain per beegah (256 to 640 ℔s. per acre), and those irrigated once or twice yield only from 4 to 8 maunds (512 to 1,024 ℔s. per acre). Irrigated three times, the crop is said to yield from 7 to 10 maunds (896 to 1,280 ℔s. per acre); but the people told me if they could irrigate four times, using abundance of water, they would get from 10 to 15 maunds of grain per beegah (1,280 to 1,920 ℔s. per acre).

Colonel Cautley states the produce in the Seharunpore and Bolundshuhur districts to be about 8¼ maunds per beegah for unirrigated, and 13 maunds for irrigated, land (1,089 and 1,702 ℔s. per acre). There is certainly a very much greater difference than this in most parts of Shahabad ; and allowing for some exaggeration in the native account above given, I think the supply and use of abundance of water to irrigate the crops would double the produce of the greater part of the district.

Watering three times in the imperfect way above described, costs as above shown about Rs. 1-9-0 per beegah (5 shillings an acre) for the season,* and it is evident that the money is well laid out. Doubling the rate of water-rent levied in the North-Western Provinces (that is charging Rs 1-4-0 instead of Rs. 0-10-0 per beegah), 4 shillings instead of 2 per acre, we should be able to supply the cultivators with

* Lieut.-Col Baird Smith (page 381, Vol. I., Italian Irrigation) makes it (omitting interest of capital) £1-11-2¼. He has, however, calculated the hire of the men and beasts for the whole year, while my calculation extends only to the period of irrigating the spring crops. Taking the irrigating season at 4 months or ⅓rd of the year, the rate comes to £0-10-4¾ The difference between this and my estimate may be owing to the greater depth of wells and the more liberal scale of irrigaton. But the wages and cost of bullocks differ greatly from those in Shahabad.

irrigation 25 per cent. cheaper than they get it now, and, in addition, give them all the advantages of four thorough drenchings for their crops instead of three sprinklings. They will, besides, have the canal supply of water all the rest of the year without any further payment, and will be able to turn it to more profitable account in raising more valuable crops than the wheat and barley, which alone I have calculated upon.

7. I found the water bags used in Shahabad hold on an average about 2¾ cubic feet of water. They were worked for short periods at the rate of about 25 per hour, but that was not kept up throughout the day, and the total number raised daily was said not to exceed 150. To be sure of making a liberal calculation I shall, however, take it at 300. This, therefore, I take as the bulk of water required for ⅗ths of a beegah (⅜ths of an acre) for one watering. For a whole beegah this gives 500 bags (800 per acre) for one watering, and 2,000 (3,200 per acre) for four waterings, or a full season's irrigation. But this is for the imperfect kind of irrigation practised in Shahabad. To irrigate thoroughly I shall suppose double the quantity of water necessary, that is, 4,000 bags or 11,000 cubic feet per beegah (17,600 cubic feet per acre).

The irrigating season in Shahabad commences about the beginning of November and terminates at the end of February. It lasts, therefore, about 120 days. Now one cubic foot of water per second for 120 days is 10,368,000 cubic feet, which will water 942 beegahs, or 588 acres. But this is the supply to be delivered from the canal, and it is necessary to add to it the quantity required to make up for the wastage in passing down the channel, in order to determine the discharge required at the canal head.

8. The following detailed calculations of the performance and cost of various irrigating machines are extracted from *Professional Papers*, Vol. I. [First Series.]

The heights assumed for raising the water in each case are those for which it is believed the several machines could be most generally and usefully employed.

The value of the modulus and the useful effect in each case are assumed after due consideration of the structure of each machine and the amount of spillage or waste.

1. *The Paecottah.*—(One man employed).

Water raised 16 feet. Content of bucket = ·45 cubic feet.
Number of discharges per minute = 3. Discharge per hour = 81 cubic feet.
If we take the useful effect or discharge at 90 per cent., we get—
Actual discharge per hour = 72·9 cubic feet = 455·4 gallons.

2. ***Baling.***—(Two men employed).

Water raised 5 feet. Deliveries in each minute = 20.
One delivery = ⅓ cubic foot. Delivery per hour = 400 cubic feet.
If useful effect = 75 per cent., then—
Actual discharge per hour = 300 cubic feet = 1890 gallons.

3. ***The Single Mót.***—(One man and two bullocks employed).

Water raised 40 feet. Speed of bullocks = 2 miles an hour.

Space gone over by the bullocks at one lift = 80 feet. Content of bag = 3 cubic feet.

Time required for bullocks in turning = ·4 minute.

Number of lifts per minute = 1·18.

Discharge per hour = 213·6 cubic feet. Useful effect = 70 per cent.

Actual discharge per hour = 149·5 = 924 gallons.

Taking the modulus = ·9 and the weight of the rope and bag = 42 pounds, the required traction which the bullocks have to overcome is = 255 pounds.

4. *The Double Môt.*—(One man and two bullocks employed).

Water raised 40 feet. Speed of bullocks = 2 miles an hour.

Diameter of barrel = 3 feet. Diameter of bullock walk = 16 feet.

Number of turns of bullock per minute = 3·4.

Total time for raising the bag = 1·4 minute. Content of bag = 3 cubic feet.

Dischage per hour by 2 bags = 252 cubic feet. Useful effect = 65 per cent.

Actual discharge per hour = 165·8 cubic feet = 1045 gallons.

Ratio of power and weight = 3 : 16. Total weight to be raised = 460 pounds.

Taking the modulus = ·7, we get—Work applied = 657 pounds.

Required traction = 124 pounds.

5. *The Single Persian Wheel.*—(One man and two bullocks employed).

Water raised 40 feet.

Diameter of driving wheel = 4 feet. Diameter of bucket wheel = 4 feet.

At each turn of the bullocks, 6 buckets are emptied, and assuming the content of each bucket = $\frac{1}{8}$ cubic foot, we have—Discharge at each turn = $\frac{3}{4}$ cubic foot.

Length of bullock walk = 62·8 feet, and speed of bullocks = 2 miles an hour.

Number of turns per minute = 2·8. Discharge per hour = 126 cubic feet.

Useful effect = 55 per cent.

Actual discharge per hour = 69·3 cubic feet = 429 gallons.

Buckets are 2 feet apart. Number of buckets required = 40.

Weight of buckets = 80 pounds.

20 buckets being always full, the weight of the water they contain is = 156 pounds. Weight of rope = 22 pounds.

Total weight to be raised = 258 pounds. Ratio of power and weight = 1 : 5.

Modulus = 0·6. Work applied = 430 pounds.

Required traction = 86 pounds.

6. *The Double Persian Wheel.*—(One man and two bullocks employed).

Water raised 40 feet. Proportion of gearing = 2 : 3.

Diameter of driving wheel = 5 feet, pitch = 3·92 inches, cogs = 48.

Diameter of bucket wheel = 3 feet 4 inches, pitch = 3·92 inches, staves = 32.

At each turn of the bucket wheel 8 buckets are emptied, the 2 wheels empty 24 buckets at each turn of the bullocks.

Content of bucket = $\frac{1}{10}$ cubic foot.

Therefore: Discharge of water at each turn of the bullocks = 2·4 cubic feet.

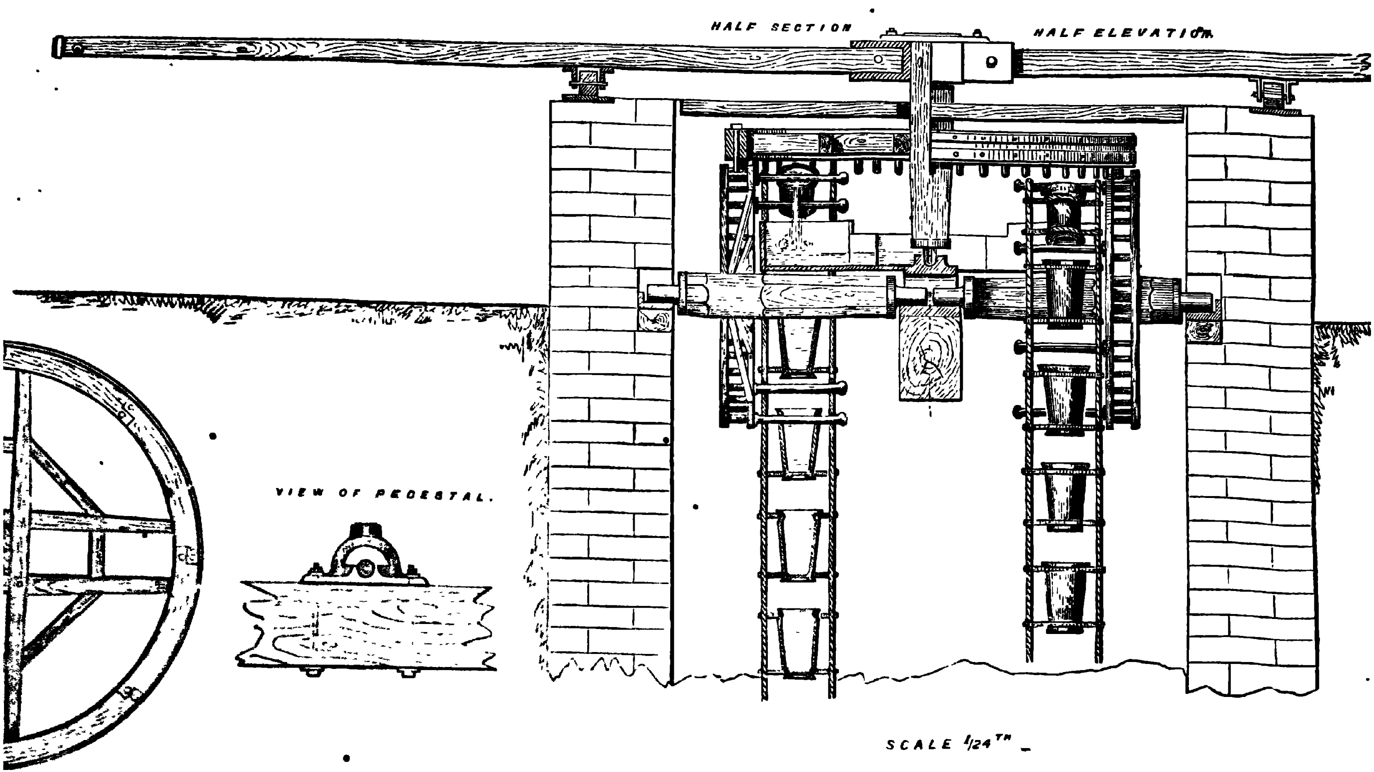
If the bullocks work on a lever of 12 feet, the length of the bullock walk is = 75 feet, and taking their speed at 2 miles an hour, we get—

Speed of bullocks per minute = 176 feet.

Number of turns per minute = 2·3. Useful effect = 60 per cent.

THE PERSIAN WHEEL.

IMPROVED PERSIAN WHEEL.



SCALE 1/24TH

Discharge per hour = 198 cubic feet = 1242 gallons.

The buckets are 1 foot 3 inches apart, and the well being 40 feet deep, the requisite number of buckets for each wheel will be = 60; 30 being always full on each wheel, the weight of water on both wheels is = 6 cubic feet = 375 pounds, which is the total weight to be raised, as the weight of the buckets and ropes are not taken into calculation, on account of their balancing each other.

Ratio of power and weight is = 10 : 48.

Taking the modulus of the machine at ·5, we get—

Required traction = 156 pounds.

TABLE SHOWING THE COMPARATIVE PERFORMANCE AND COST OF THE ABOVE MACHINES IN RAISING WATER TO THE SAME HEIGHT (40 FEET).

The expense of a laborer is put down at 2 annas, and of a bullock at 4 annas per diem. Duration of work per diem = 8 hours.

No.	Methods.	Stages.	Useful effect per cent.	Discharge per hour.		Discharge per diem.		Ratio of discharges.	Employs		Daily expense	Quantity of water raised for one rupee.		Remarks.
				Cubic feet.	Gallons.	Cubic feet.	Gallons.		Men.	Bullocks.	Annas	Cubic feet.	Gallons.	
1	Paccottah, . . .	2·5	90	29 07	181·4	232 5	1451·5	1	2	...	4	930	5806*	Discharge increased with decrease of height.
2	Baling, ...	8	75	37 5	*236 2	300	1875	1·29	4	...	8	600	3750	Ditto.
3	Single Mót, . . .	1	70	149·5	924	1196	7392	5·1	1	2	10	1911·8	11827·2	Ditto.
4	Double Mót, . . .	1	65	165 8	1045	1326 4	8360	5 7	1	2	10	2096·6	13478·5	Ditto.
5	Single Persian Wheel,	1	55	69 3	429	554·4	3432	2 4	1	2	10	887	5491	Discharge the same at any height.
6	Double Persian Wheel,	1	60	19·8	1242	1704	9936	6·8	1	2	10	2534·4	15897·6	Ditto.

* Being $\frac{1}{8}$th of the quantity raised 5 feet high, as computed at p. 7.

The cost and wear of the machines are not taken into consideration. No. 1, or the Paccottah, is taken as a unit for the ratio of discharges.

CHAPTER II.

CANAL IRRIGATION—INUNDATION CANALS.

9. CANALS are divided into two great classes, those of Irrigation and Navigation. The conditions required to develope one of the former class successfully are—1st, That it should be carried at as high a level as possible, so as to have sufficient fall to irrigate the land for a considerable distance on both sides of it; 2nd, That it should be a running stream so as to be fed by continuous supplies of water from the parent river, to make up for that consumed in irrigating the lands.

The conditions of the latter are, on the contrary, that it should be a still water canal, so that navigation may be equally easy in both directions; and, as no water is consumed except by evaporation or absorption, and at points of transfer from a higher to a lower level, the required quantity of fresh supply is comparatively small, and it is thus most economically constructed at a low level. An irrigation canal, however, may and should be as a rule, laid, out so as to serve for navigation as well; the velocity of the stream being made as gentle as is consistent with its primary uses, so as to afford facilities for boats ascending against it as easily as possible.

10. It is of Irrigating Canals, as forming the more important class of the two, at least as regards India, that the ensuing Chapters will principally treat. In England they are unknown, as the rain-fall in that country is so considerable, that the operations of the farmer are principally directed to draining the superfluous moisture from the soil. In Italy, where the climate is hotter and drier, there are many fine canals, of which the late Colonel Baird Smith has given an interesting record to the profession. In India they have been used from time immemorial; and at the present day, Engineers, aided by experience of the past, are proceeding rapidly in the development of these useful works, which so

largely contribute to the productive powers of the soil and to the security of the country from famine.

But, it is only of late years that the true principles on which such works should be constructed have been properly studied, or at all understood. The first canals opened out by us in India were those which had been made two or three hundred years ago, in the times of the Mahomedan Emperors, and which had become useless by neglect. The alignment of these was, in all cases, very defective, and as money could only be spared from time to time for their improvement, cheap and temporary expedients were resorted to, to bring them into use, and make them pay as quickly as possible. At first, too, our Engineers, had no experience of such works, nor was there any available quarter from which it could be derived. Much, therefore, was done by "rule of thumb," until the laws of running canals may be said to have gradually worked themselves out. On the Ganges Canal, for the first time there was new ground to work upon, and Sir P. Cautley and his able assistants, successfully overcame the difficulties attending that vast project, but much was developed during the actual construction of the work, and, if it had to be done over again, much would doubtless, be improved. The Baree Doab Canal, in the Punjab, (also an entirely new work,) was commenced some time before the Ganges Canal was opened, and, therefore, has only partially benefitted by the improvements suggested since the opening of the latter. Even now, it may be said, that many important questions connected with canal irrigation are undecided, but the experience already gained may be fairly summarized for the use of the young Engineer, to be supplemented by his own hereafter.

11. A number of important canals have also been opened out in the deltas along the east coast of the Madras Presidency, and a canal from the Toombudra near Kurnool to Cuddapah, a distance of nearly 200 miles, is now being made by the Irrigation Company. From the nature of the country, however, any canal operations in the central part of the Peninsula must necessarily be of a more difficult and expensive character than those in the alluvial tracts along the coast, and we may therefore look upon the Godavery and Kistna Delta works as the best style of an irrigation system on a large scale that has yet been carried out; or, indeed, that is practicable on the Madras districts. The irrigation under the Cauvery in Tanjore and Trichinopoly is also very important,

but it cannot be properly classed under the category of a canal system, as the main channels which conduct the water to different parts of the delta are the natural arms of the Cauvery. The nature of these channels and the improvements which have been introduced since the district came into our possession will be explained in a subsequent Chapter.

12. Nearly all the great rivers of India are charged with silt during the rains. In the upper part of their course, where the natural fall of the country is great, and the velocity of the stream is therefore high, this silt is carried forward by the water holding it in suspension, and the action of the stream is generally erosive, and tends to lower the bed; but as the river reaches the plains below, the velocity gradually diminishes, and at last falls below that necessary to carry on the silt, which thus becomes deposited. The effect of this is to raise their beds, and cause them to be constantly shifting their course, and also to raise the ground on both sides of their banks, often for a considerable width, by successive deposits of silt when they overflow their banks. Thus, such rivers will not run in the lowest lines of the valleys, as in ordinary cases, but there will often be a considerable fall from their banks outwards. It is evident this gives great facilities for such irrigation works, as are above described.

But in the rivers of Northern India, although there is a certain width of lands on each side, (known as the *Khadir*,) which has been formed, as above; yet, it is, in general, a very narrow strip. The greater portion consists of a high table land, (the *Bangur*,) occupying nearly the whole extent of the Doab,* and generally rising very abruptly from the *khadir*. It is, therefore, impossible to irrigate this high land by a short cut from the river; the depth of digging would be too great, and the water would never stand at a sufficiently high level to be brought on to the land except by expensive apparatus for raising it. It is necessary to go back to a point high up in the river's course, whence the water can be brought on to the high land by excavation of a moderate depth, and by which sufficient command of level may be obtained to overflow the surface.

The land, in Upper India, bears two crops a year, the *Rubbee* or spring crop, which consists chiefly of cereals, and other productions of

* Doab, *do* (two), *ab* (water). Country between two rivers.

temperate climates; and the *Khureef* or autumn crop, which consists of rice, sugar, and other tropical products. As the rivers are at their highest when the *khureef* requires water, so obviously, it is much easier to irrigate this crop; which, however, generally gets a liberal supply from the falling rain. But the *rubbee*, which is by far the more valuable, requires water when the rivers are at their lowest, and rain is always uncertain.

13. After the above explanation, we may now proceed to describe the simplest kinds of canals used in Upper India, which are generally known as *Inundation Canals*, of which there are many existing along the borders of the Punjab rivers and in Sindh by which the *khadir* or low land is irrigated. Cuts are made from the river inland, for a certain distance, and are then carried in a direction generally parallel to the fall of the country, or the course of the river. By these, when the latter is in flood, the autumn crop is watered. Alos before the river floods subside the canals give the means of inundating some of the lands intended for the wheat and other spring crops, the further supply required to bring them to maturity being raised from wells. But owing to the depth of the spring water increasing with the distance from the rivers, the almost total absence of rain and the insufficient number of canals, a very small proportion of the fertile alluvial tracts in the valleys of the Indus and its tributaries is at present under cultivation. During the cold season, laborers are employed to clear the canals of the silt which was left by the waters in their beds or heaped up at their mouths, varying from 1 to 6, or even 10 feet in depth. The irrigation is carried on by means of branch canals leading from the main one, whence the water is carried by minor channels on to the fields. When the levels do not admit of surface irrigation, the water is raised from the canal itself by the Persian wheel, or a temporary dam is placed across the channel to raise the level. Many of these canals have been made for the last 300 years, and are still in good working order, though kept so only by continual labor; their course is very crooked, following every winding of the ground, having been, in fact, laid out without the use of levelling instruments. The main channels vary in length from five to fifty miles, but they are generally too narrow for navigation.

14. No fee or tax is usually levied for the use of the water, but it

was the custom under the native Government to clear out the canals by statute labor, the number of laborers being assessed among the different land-holders, in a rough proportion to the areas of the lands irrigated, and the practice is still generally continued in the Punjab, though in Sindh money payments for the work done were introduced some years ago.

The following Statistical Table, (page 16) prepared in 1858 for the Mooltan inundation canals, may be interesting :—

15. There are no works at the head to control the supply of water, for the course of the river is so uncertain, that it may completely desert the head, and the water may have to be brought in by a new mouth excavated for that season, which again may be useless in the next, or the bank of the river may be cut away to such an extent as to involve the head works in its fall. Under any circumstance, there is always a considerable deposit of silt at the head, which would naturally be increased by anything in the shape of a dam.

The silt excavated from the bed during the cold season, is usually heaped up close to the edge in rough spoil banks, and is constantly falling in, while the tortuous course of the channel also causes large deposits of silt at the bends. The accumulation is still further increased by the water having no exit at the tail of the canal, which usually terminates in a series of small channels in the middle of the district. The labor of clearance thus becomes a heavy annual charge or draw-back on the benefits received from the water, and the numerous deserted channels in various parts of the country show that, without such labor, these canals would soon silt up and become useless. But, in spite of all defects, they are highly prized by the people, and the Government has, at different times, made large grants of money for improving some and opening out others.

Their nature and the direction which such improvements should take, will appear further on, as we treat of permanent canals. They may briefly be said to be, straightening the course, thorough clearance of the channel with due attention to the slope of bed, improvement of the banks and proper disposal of the spoil earth ; and, finally, where feasible, establishing a control over the water at the head, and giving it a free outlet at the tail of the canal.

16. The following paragraph is extracted from a Memo. by the late

COMPARATIVE STATISTICAL STATEMENT SHOWING IN ABSTRACT THE AMOUNT OF IRRIGATION, REVENUE, "CHER" LABOR, &c., &c., FURNISHED BY THE INUNDATION CANALS OF THE MOOLTAN DISTRICT.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Canals.	No. of villages.	Length in miles.	No. of cuts (" kussees.")	Irrigated area in acres.	No. of wells, jalors, &c.	Total canal juma.	No. of " chers " on canal.	Average rate per acre of canal juma.	Average No. of miles of annual clearance to each " cher."	Average No. of irrigated acres to each " cher. "	Average No. of wells to each " cher. "	Money value of " chers " labor as shown in column 8, i.e., " abeeanah.	Average rate per acre of " abeeanah," on irrigated area.	Average rate of " abeeanah " on each well, jalar, &c.	Percentage of " abeeanah " on total canal revenue.
Chenab canals, ...	326	219	1,402	75,766	3,095	128,835	2,065	1-11-2	9·43	36	1·50	30,825	0-6-6	9-1-6	24
Sutlej canals, ...	540	440½	888	93,413	4,355	105,685	3,880	1-2-1	8·81	24	1·12	58,200	0-9-11	13-5-10	55
Total, ...	866	659½	2,290	169,179	7,450	234,520	5,945	1-6-2	9·01	28	1·25	89,025	0-8-5	11-15-2	85

(Signed) J. H. MORRIS,

Settlement Officer.

Col. Anderson, R.E., on Irrigation in general, and Inundation Canals in particular, and will be found to repay careful perusal :—

Irrigation by means of canals is chiefly applied to tracts of country which have been formed by the gradual deposit of alluvial matter, from rivers in a state of flood. The deposit from the inundation begins to take place at the points where the velocity of the stream is checked ; and this being along the margin of the channel, an inundation of the country through which a river passes will leave behind it on each side a stratum of silt in the form of a wedge, the thick end of which is on the river bank.

In the course of time, successive annual inundations will thus have formed a slope away from each of the banks, resembling the glacis of a fortification.

The width of this slope, will vary according to the nature and size of the river. It may be only 200 or 300 yards, and be perceptible to the eye, or it may extend to the distance of many miles.

The feature above described is not only to be found along the main channel of a river, but also along its branches. No very extensive tract of country has been formed by the inundation and consequent deposit from a single stream. On the contrary, it must have been the work of many.

The channels of all rivers, unless when confined by rocks, have been more or less liable to change their course. By referring to a map of any delta, the reader will observe that the characteristic of the Delta form, is that a river as it approaches the sea, should split up into two or more branches or arms, which again may be subdivided into smaller ones. Each branch has a tract of country within its influence, and serves to extend the amount of alluvial deposit, either by raising its banks, or by extending the Delta seaward.

It is a common occurrence to find dry beds of rivers in alluvial plains, possessing all the characteristics of the existing channels. In some cases, channels may be found of such capacity as to show without doubt, that they are deserted beds of the main stream ; in others, there may be indications of a partial and gradually diminishing supply having reached them, which, by successive annual deposits, has curtailed their section to such an extent as to admit of their being adapted as irrigation channels, or if left entirely in their natural state, such channels may be silted up completely by successive deposits from flood water and by drifted sand and dust, until they are no longer perceptible, and all that is left to mark their course is a ridge of high land.

It will thus be seen that an alluvial plain (so called) is not made up of an equable deposit of alluvial matter to the right and left of the main channel of a river, but on the contrary, by that from a number of channels, some of which may subsequently be obliterated. The fall of the country also, instead of only following the course of the main channel, will be affected equally by all the others. Intermediate between the channels, the ground will be low, and the line formed by the intersection of the two planes sloping away from their respective banks, will evidently indicate the course in which the drainage from those plains will tend to flow. Such lines will be found also on the extreme boundaries of a delta,—receiving on one side the drainage of a portion of the delta, and on the other that of the country independent of it.

17. After these remarks it is time to explain that the irrigation of a tract of country is based on very simple principles. Supposing that a supply of water is required for the land near the bank of a river, which has ceased to over-flow it,

but which may rise to the lip of the channel, then as the country falls away from the river, it will be readily understood that a cut through the bank will give the means of irrigating the ground beyond. This may be considered the simplest form of irrigation. Again, if the surface of the river falls so considerably below the lip of the channel, as to be incapable of supplying water to the ground at a distance, by means of a cut carried at right angles to the course of the river, the difficulty may be surmounted by excavating a channel in an oblique direction; for the course of a river is never straight, and an artificial channel may be formed in a straight line, which will carry the water to a higher level than that of the surface of the river at any point opposite to it. For every mile of its course, it thus gains something on the surface level of the river, and it becomes a matter of simple calculation to find how far it will have to be carried, before the water issues on the surface. For instance, if the fall of the river surface is one foot per mile, but with a tortuous course of one-half more than the direct line, an artificial channel with a fall of one foot per mile, running parallel to the general course of the river, that is from point to point of curves, will, for every mile of cutting, gain six inches on the river. So that if the surface of the water at the head of the cut were five feet below the lip of the channel, it would gain that amount on the river in ten miles.

If the cut were excavated in ground on the same level as that on the margin of the river, the water it carried would then come to the surface and be available for irrigation; but as the ground falls at right angles to, as well as with, the course of the river, the required level would be attained by a cut less than ten miles in length; or if the fall along the cut were less than one foot per mile, say six inches per mile, the water would come to the surface in five miles, or less according as the ground might be level, or slope off in the direction of the cut.

It will be readily understood that the high ridges and the old channels, above described, indicate the most suitable alignment for a series of Irrigation channels. The object would be to conduct the water from the river to the crest of such high lands, and then, for the channels along them, to arrange as far as may be practicable that the excavation shall be no more than sufficient to furnish the material required for the embankments, which should retain the water at as high a level as possible, consistent with their stability. If the depth of water admitted into the head of the main channel is materially less than what is due to the river at its full height, the depth of the excavation at the head will increase in proportion to the difference; and it will then be an object, in order to make the cutting as inexpensive as possible, to carry the line of the channel through low ground, until the water would flow on the surface. The irrigation limit is then reached, and the channels should be continued along the highest ground that will allow of the water continuing on the same level with it or above it, as may be found most suitable for the locality. If the ground were level on both sides of the channel it would in many cases be indispensable to have the surface of the water above it; but on the other hand, the soil may be ill-adapted for withstanding pressure, or for preventing percolation; and to avoid the occurrence of breaches, it may be desirable to keep the height of the embankments within very moderate limits.

18. *Heads of Inundation Canals.*—A channel opening direct from a river and unprovided with a sluice or other regulating work at its head, is subject to the two following disadvantages. It is subject either to have its supply increased

to an inordinate extent during high freshes, or to have it cut off altogether. In one case the current of the river may set on the mouth of the canal or on the bank above it. If the soil is liable to erosion, it will be cut down and washed into the canal: the head of the canal itself would be enlarged; and such destructive action would only be limited by the duration of the fresh. The greater the fall of the canal in this case the greater the evil. Or, on the subsidence of the higher freshes, the stream may have moved to the opposite bank of the river, leaving a mass of sand banks between it and the head of the channel, which it would be impossible to cut through in time to restore the supply. In this case, the *less* the fall of the channel, the greater the evil. Both the above contingencies must be common in all Irrigation channels which are opened from a river with a shifting bed. In the latter, a temporary bund may in some cases be effectual in replenishing the channel, but it has generally to be constructed before the freshes have finally ceased, and is very liable to be destroyed just as it is completed. Though a new head may be formed through the sand banks for the next season, it is next to impossible to cut through them at the close of the rains, with a falling river, and when the water under the surface of the sand bank stands on a higher level than that of the river.

The violent action on the mouth of the channel when the river sets against it, may be checked by revetments, groynes and such like defences, but they must also have the effect of diverting the action of the stream from its natural course, and thus tend to throw it off towards the opposite bank. Supposing that there were no other difficulties to surmount but the two I have specified, they might be overcome by the construction of a head sluice, with defences against encroachment, and of a groyne running from the opposite bank, so as to force the stream of the river to pass alongside the head sluice. In many cases, however, construction of such a groyne would be impracticable. The river might be too large, suitable material not procurable, and the expense of maintenance of the groyne itself, and the river defences which it would necessitate, would be too great to be justifiable, unless the channel were of very high importance,—and in that case, a dam or anicut across the river would be more suitable, as well as efficacious, than a groyne.

19 It is an object of high importance to fix the heads of channels in positions where they will be least liable to silt up, in order that they may have no greater obstacle to contend with than what is inevitable,—that is, the chance of an insufficient height of the freshes. Unfortunately, unless in a river which flows in a permanent channel, it is impossible to find a site where the head of an irrigation channel will not be exposed to silting. The advantages of any sites will only be relative: no general rules, either, can be laid down for selecting them; so much must depend on local peculiarities, that what might be sought after on one river, would have to be carefully avoided on another. It will depend on the nature of the soil, fall, &c., and the height of the water, whether it is advantageous or otherwise to expose the head of a channel to catch the full effect of stream in the river. In some places this might be a desideratum, in others, it would simply destroy the channel.

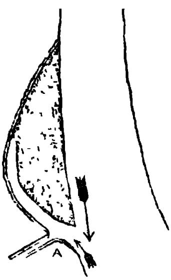
I will therefore confine myself to a few observations on particular cases in which I have found channels to be defective or otherwise.

When opened so as to have the stream in the river bearing on the head as much as possible. If the soil is not extremely tenacious, the banks at the head of the channel will be washed down, and the material thus displaced will block up the channel. If the sides of the head are revetted, a great part of the evil may be averted, but it

will be found that this will not prevent sand banks accumulating in front of the mouth, and if the stream acts on the bed, a large quantity of material may be carried forward to the lower portions of the channel.

If a canal is opened from a bank which the river shows a tendency to set against and cut down at any point above the head, then there must be evident danger of the canal being choked up by the material which would be washed down.

In the case of a river which is liable to occasion mischief of this kind, the most suitable point for opening a channel is where there will always be a sufficient depth of water without any violent stream acting on the banks. Perhaps the most suitable of all conditions would be if the river passed at right angles to the head of the channel, but as there could be no certainty of its continuing in that direction, it would be better to avoid such a site, and to select one where the water would be comparatively stagnant. For instance, if the river flows in the direction shown in the adjoining diagram, after receding from a curved channel, which it may have formerly cut for itself by encroachment on the bank, or if A be the tail of a creek or arm of the river which leaves the main channel at some point higher up, there will be a backwater there, and, although the stream may pass over the sand bank or island with considerable velocity in the freshes, it will be less than that of the main stream, and less likely to do mischief. The point A would therefore be a good site for the head of the irrigation channel. It must be observed that the backwater may be of recent formation, and that its mouth may tend to advance downstream, so that care should be taken to have the head of the channel sufficiently low down to guard against the contingency of the channel in front becoming dry, and at the same time not so low as to bring it within the influence of the main stream.



It will frequently be found that there is no eligible site for the head of a channel in the bank of the river in an interval of many miles. The river may have receded towards the opposite bank, leaving a mass of sand banks between it and the point where the channel may be required. In such cases, however, there is generally the dry channel of the river or of a branch of it, running along the foot of the bank, and it may be necessary to follow it up to its head, and perhaps to clear it, in order to make use of it as an artificial channel. The head of such a channel, if there is any choice on the matter, should be selected on the same principle as that of an artificial channel, care being taken to hug the bank as much as possible, or at least to remove all the soil excavated, to the side which will be furthest from the action of the stream in freshes, or it would otherwise be washed into the channel.

In some cases there may be no alternative, but to cut through the head of a sand bank with the knowledge that the effect of any excavation will only be temporary. There will then be great danger of the supply failing when the river subsides, and should it do so, there will be no remedy, unless it may be that the creek leading to the canal may be large and may derive a partial supply, though on too low a level to suffice for the wants of the canal. In this case, a bund across it immediately below the head of the latter may be of some service.

20. *Head Sluices.*—If the canal is to be furnished with a sluice, it should be constructed as near the head as is consistent with its stability. If the bank

of the river, and the head of the channel can be rendered secure against injury at a moderate expense, by means of revetments or groynes, the efficiency of the canal would be much promoted by constructing them ; but if the river is not tolerably permanent, and there is the likelihood of the canal head being left at times high and dry, with the necessity of opening a new head at some point higher up or lower down the river, the sluice and works connected with it would be rendered useless. When however there are no such disadvantages to contend against, it would seem highly desirable that every channel should have its head sluice, in order that any excessive supply of water may be prevented from entering. Unless it is built at the head of the channel, this advantage cannot be obtained without the inconvenience of a deposit of silt in the channel between the head and the sluice. The extent of this will of course depend on the height of the water, and the time during which it is held up by the sluice. If the interval between the sluice and the head is considerable, this evil would be serious ; and in many cases, it would be better to construct the sluice at the head, with the chance of its being destroyed. This, however, is a question to be decided separately for each case on its own merits. If a sluice is required to prevent inundation, and if disastrous effects would ensue from its destruction, it might be advisable in such cases to have a second sluice in reserve, at a sufficiently safe distance from the head.

21. *Slope of Bed.*—Where the fall of the country is tolerably uniform, the slope of the bed of the main channel should be less than that of the branches, which again should be less than that of the minor channels and cuts. The object of this is to secure as far as possible a uniform velocity, so that the alluvial matter held in suspension may be carried on from the head, and deposited uniformly over the lands irrigated.

As to the actual fall which should be given to the main trunk of a canal, apart from the consideration of expense or in fact any considerations, but that of the maintenance of the channel in good working order, I would name 6 inches per mile, in preference to any other, for alluvial soil of moderate tenacity—on the supposition that the depth of water will be from 6 to 10 feet, and the width considerable (say 100)—being nearly the same that I have observed has been adopted by channels in their natural state, in similar soil. I would by no means insist on this being the best fall in all cases.

I assume the slope of bed to correspond with the slope of surface, but it may be desirable to cut down the head of the canal, so as to yield a smaller slope of bed, in order to obtain a supply of water at an earlier date in the season. But the bed always tends to follow the slope of surface, as will be obvious from the consideration, that if the depth is greater towards the head than it is at some point lower down, the velocity (supposing the width to be the same) will be less, and silt will consequently be deposited until the velocity throughout becomes uniform. Such a diminished slope at the head must therefore render necessary a considerable annual clearance. In some cases it may be desirable to reduce the width at the head in order that, with an increase of depth the velocity may be the same as that in the channel lower down, but a smaller supply than before would then enter the channel when the river falls below the normal level.

22. On the assumption that a surface fall of 6 inches a mile, or say 1 in 11,000, is suitable for the main channel at starting, with a width of 100 feet, I proceed

to show the rate at which the fall should be increased as the supply becomes less.

Let us suppose that branches are drawn off, taking a certain proportion of the water, and that the width of the main channel is reduced by successive degrees to a width of 80, 60, 40, and 20 feet, and that the depth is reduced successively to 5½, 5, 4½ and 4 feet, but that the velocity throughout is maintained at what it had at starting with a width of 100 feet, depth 6 feet, surface fall 5·7 inches per mile,—namely, 2·1 feet per second. By means of the hydraulic formula, I find the fall of surface required in the different cases will be 6·4, 7, 7·9, 10, 3, inches per mile. From the terminus, let a channel leave with a depth of 3 feet and width of 10 feet, reduced after consumption of a portion of the supply of water, to a width of 6 feet and depth of 2½ feet; the velocity to be the same as before. The fall required for these channels will then be 14·8 and 19·5 inches a mile; and if we suppose the length of each of the first mentioned channels, or reaches of channel, to be 10 miles, and that of each of the two last to be 5 miles, the whole fall from the head will be somewhat more than 45 feet, and the whole distance being 60 miles, the average would be 9 inches per mile. If the fall of the country did not admit of so high an average, it might be easily reduced by maintaining a greater depth in the channels and diminishing the width. *If for instance, in the case above-mentioned,* the depth for 50 miles had been maintained at 6 feet, the total fall required would only have been 26 feet, or on the average 6¼ inches per mile.

23. The above will be sufficient to indicate the mode in which the slope of the channel should be regulated in order to prevent accumulations of silt. In practice, a canal is never perfectly aligned on this principle, but unless it can be shown to be defective, as I have no reason to think can be done, every endeavour should be made to adhere to it, in designing a system of Irrigation works, so far as local peculiarities and othere circumstances permit.

The accumulation of silt in channels, particularly in the main channel, is not only a serious impediment to maintaining a supply of water till the crops are matured, but the clearance may be enormously expensive. Even if the silt cannot be carried on to the fields, as in a perfect canal, at least one step in advance is gained, if it is prevented from accumulating in the main channel; for the maintenance of the supply in it is the most essential point, and if there are deposits in the branches only, it may be possible to clear them in turn, without cutting off the supply from the river; or if this might not be feasible with the branches, it would be so at all events with the smaller irrigation channels; and it would not only be advantageous to throw on the silt to them, and to clear them in turn, without cutting off the supply of water from the branches, but the clearance would evidently be much less costly from them, than it would be from the larger channels.

When the fall of country is so gentle as not to allow of the fall of the channels being gradually increased from 6 inches a mile, it would be necessary to reduce the initial slope somewhat. A very slight reduction, would, as it affects the whole of the channels onwards, in the aggregate, amount to something considerable.

If, on the other hand, the fall of country be too great, the initial slope may be increased, with, if necessary, a reduction in the depth of water; or if the fall of country is rapid at first and afterwards more gentle, the desired result may be obtained by constructing perpendicular drops at intervals.

Any change of direction causes a certain loss of velocity, and the water thrown into branches and minor channels would lose velocity, in passing through the head-sluices, unless they possessed the full water-way of the channel. Due allowance would have to be made for this by adding somewhat to the slope at the heads of the branches and channels.

The principle above described of the necessity of keeping up the velocity to the point of the delivery of the water, is so obvious, that it must have occurred to every one, who has had much to do with Irrigation works ; and I should not have thought it necessary to dwell upon it at such length, had I not reason to believe that it is very much lost sight of in practice.

CHAPTER III.

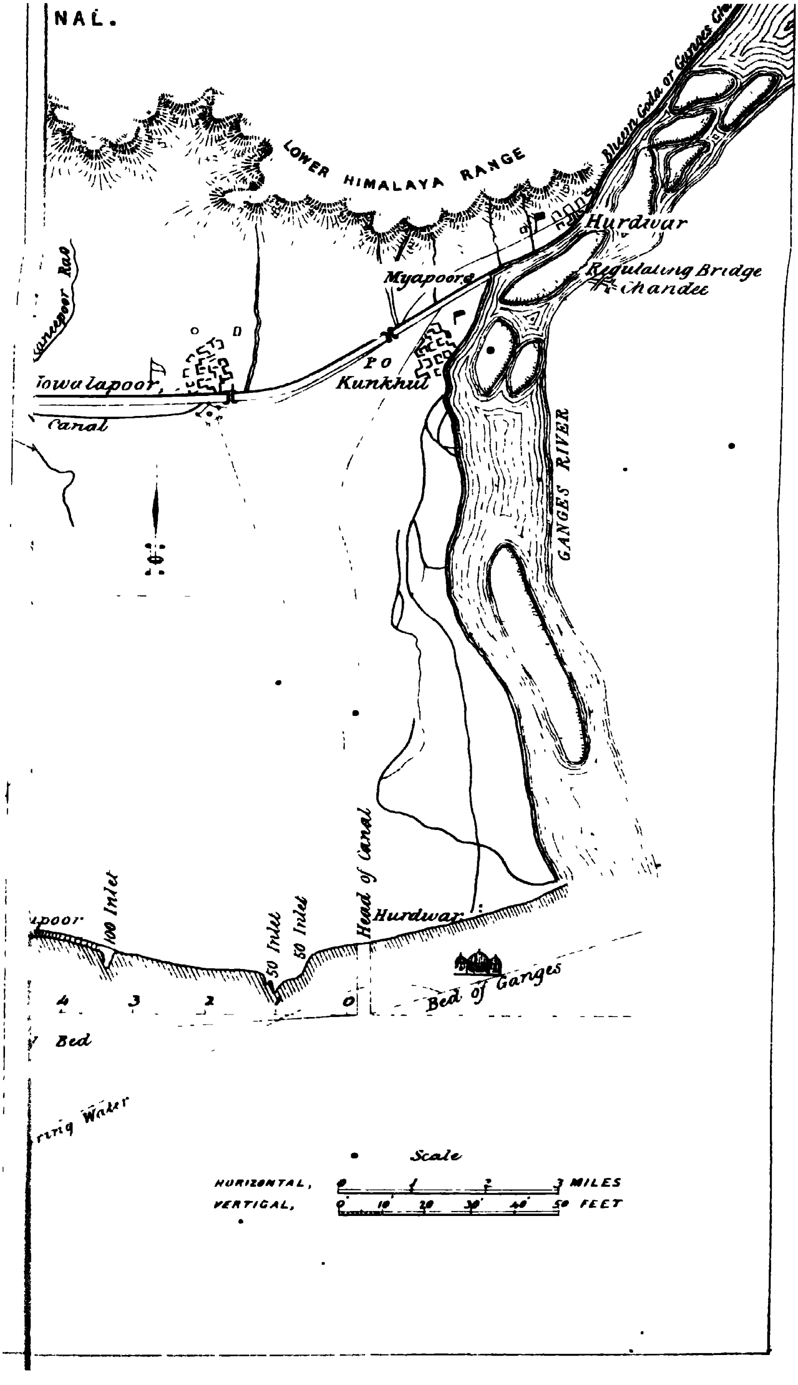
PERMANENT CANALS—SOURCE OF SUPPLY—AMOUNT OF WATER REQUIRED—SLOPE OF BED—SECTION OF CHANNEL—ALIGNMENT OF CANAL.

24. We now come to Canals of Permanent Supply, of which the greatest examples now in use are the Ganges, Baree Doab, and the East and West Jumna Canals.

The first point to be considered in designing such a work is, *the Source of Supply*. This will always be a river carrying a perennial stream (in Northern India fed by the snows of the Himálayas); and the only question is, at what point in the river's course we shall take off our supply, *i. e.*, fix the head of our canal?

From what has been said above (para. 12) it will appear that this point must be high up on the river's course, so as to obtain plenty of command of level, and get on to the high ground without much heavy digging; and it will generally be found, that for this purpose, it is necessary to go either to the spot at which the river finally leaves the hills to flow through the plains, or to a point, at any rate, not far below that spot. Moreover, at this point the water (except in freshets) is pure and free from silt, the great enemy of canals, and the course of the river is restricted within narrow limits, so that by dams thrown across the river bed, we can easily divert the water into our new channel.

The above considerations are so important, or rather, peremptory, that they outweigh the disadvantages of the arrangement which are, indeed, very serious. For, the country so close to the hills having generally an excessive fall, and being, moreover, intersected by hill torrents, the carrying of the canal through such irregular ground entails serious difficulties, which require the greatest engineering skill and a large expenditure of money; to overcome them.



NAL.
LOWER HIMALAYA RANGE
Hurdwar
Regulating Bridge
Chandee
Myapoore
P O
Kunkhul
Jowalapoor,
Canal
GANGES RIVER
Head of Canal
Hurdwar
100 Inlet
50 Inlet
50 Inlet
Bed of Ganges
4
3
2
0
Bed
Scale
HORIZONTAL, 0 1 2 3 MILES
VERTICAL, 0 10 20 30 40 50 FEET

The selection of the exact spot for the head of a canal is a task requiring much careful consideration. The chief principles by which the selection will be determined, besides those already indicated, will appear as we proceed.

25. The next question is, *How much water do we want?* for on this depends the size of our canal; and this is determined partly by the area of land to be irrigated, and partly by the quantity of water that can be obtained from the river when at its lowest. In Northern India, however, the area of land requiring irrigation being practically unlimited, the question becomes, "How much water is available from the river or source of supply at its lowest?" For though at first sight it might appear feasible to make the canal channel large enough to carry an extra quantity of water when the river had plenty to spare, experience has *proved that as this extra water would be available for one crop only, and that the less valuable one,* the advantage of this arrangement would not generally compensate for the extra cost required to be incurred on the channel and masonry works.

It is evident that the effective work of a cubic foot of water discharged from the canal, for irrigating the land, must depend upon variable data, such as the nature of the soil and the crop, the distance the water has to be carried on to the land from the main channel, the humidity of the atmosphere, &c.

The average assumed for drawing out the projects for the Baree Doab and Ganges Canals (derived from data afforded by the Jumna Canals) was, that each cubic foot per second of discharge was capable of actually irrigating 218 acres; and reckoning that for each acre actually watered there would be two other acres either lying fallow or being watered from wells or rain, then each cubic foot would represent 654 acres, (say one square mile,) of culturable land, more or less dependent on the Canal. In the Soane Canal Project (1861), Col. Dickens reckons three-fourths of a cubic foot of water per second, for every square mile of gross area.

By the Report of the Chief Engineer of Irrigation, for 1868-69, each cubic foot on the Eastern Jumna Canal, on which the irrigation has been most fully developed, actually waters 306 acres; in the same year on the Ganges Canal on which the irrigation is still in course of development, the irrigating duty per cubic foot was only 232 acres. In

Tanjore, one cubic foot per second of discharge is reckoned sufficient to irrigate 40 acres of rice. Our canal data are as yet too imperfect to be able to speak precisely on these points, and it is evident that the conditions are very varying. So long as the present system is continued of paying for irrigation according to the area watered, and not according to the amount of water taken, it is evident that there will be great waste.

26. The method of calculation adopted by Sir P. Cautley in the Ganges Canal, was to reckon the expenditure of water per lineal mile of canal, which from practical data was taken to be 8 cubic feet as the maximum. In the Sutlej Canal project, 6 and 7 cubic feet have been taken. This, however, pre-supposes that the main and branch lines have previously been fixed upon; it is a very convenient form of calculation, as it enables us to regulate the size of the channel along the whole course of the canal, diminishing it as the water is gradually expended.

If the canal is to be a navigable one, a certain minimum depth must be assumed everywhere, so that the amount of water required for that minimum must be allowed over and above the quantity to be expended on irrigation. On the Soane Canals, 600 cubic feet per second have been set apart for navigation alone; on the Baree Doab Canal, 130 feet; on the Ganges Canal, 400 cubic feet.

A large area of the land through which the canal takes its course may be unfit for cultivation. The soil may be bad or swampy, or it may be reserved for forest or grass preserves, or occupied by towns or cantonments. All this has, of course, to be taken into consideration in fixing the area actually available for irrigation, whence the amount of water required must be determined.

27. Suppose we desire to irrigate a particular district, say 200 miles long and averaging 40 miles broad, lying between two rivers, by cutting a canal from one of them, and carrying it along the watershed of the country. The total area of such a district would be 8,000 square miles. Now of this our maps would show us (say) that 1,500 square miles were *khadir* land, which could be irrigated by wells or by small canals cut from the river, leaving 6,500 square miles of *bangur* to be provided for, from which another 1,500 would very likely be deducted for town sites, swamps, forests, &c., leaving 5,000 square miles actually

requiring irrigation. At the rate of 1 cubic foot per square mile, this would require a canal with a minimum discharge of 5,000 cubic feet per second. Or, if we reckon 8 cubic feet as required for each lineal mile, we should require 625 miles of canal; but, practically, the lines of irrigation would be first arranged on the map from the levels, and *thence the amount of water would be determined and might be compared with the area calculation.*

Should the amount of water required not be obtainable from one river only, it is possible it might be feasible to take a supply from both. If not, then the greatest amount that can be obtained from one when the river is at its lowest must, for the reasons above given, be assumed for the calculations.

28. *Width of Channel.*—The proportion of depth to width on the Western Jumna Canal, being that which the stream has in course of years formed for itself, was found by a series of trials to be about 1 in 13. On the Baree Doab Canal, the proportion fixed in construction was 1 in 15: for the Sutlej Canal, 1 in 14. It is evident, if the canal is to be navigable, that the minimum of width must always be sufficient to allow of two boats passing each other, while a minimum of depth (usually $2\frac{1}{2}$ feet) must also be allowed to float the boats.

The side slopes of the canal channel will be arranged generally according to facilities for excavation, for unless the slopes are made very flat, or are turfed at a great expense, the action of the water will in ordinary soil quickly cut them to the shape at which they will ultimately stand firm.

29. Having determined the quantity of water, and fixed the proportion of depth to width, and a minimum for both, chiefly with reference to navigation facilities, there yet remains a very important question to be determined before we can devise the section for our channel, that is the *Slope of the Bed.*

If this slope is too great, the bed of the canal will be torn up, and the foundations of all bridges and other works will be endangered. Besides which, the difficulties of navigation against the stream will be largely increased.

If, on the other hand, it is too small, a larger section of channel will be required to discharge a given quantity of water, and, as will be explained further on, many additional works will be required in the

shape of Falls, Locks, &c.; there will also be danger of silt being deposited in the bed, or of the stream being choked by the growth of aquatic plants.

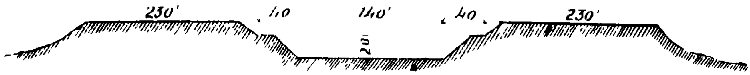
It is therefore necessary to steer clear of both extremes; but it is not always easy to do so, and in general a compromise has to be made. Moreover, as the velocity increases very rapidly with the depth, it is evident that a slope of bed which might be a very proper one for water of a certain depth, would be too great if it were necessary to increase *that depth so as to throw an extra supply into the canal.*

30. The minimum velocity required to prevent the deposit of silt or the growth of aquatic plants may be said to be about 1½ feet per second, so that if a minimum of depth be fixed, we can find the minimum of slope necessary to secure any given discharge. Under ordinary circumstances this may perhaps be fixed at 6 inches per mile, though it is occasionally even lower than that.

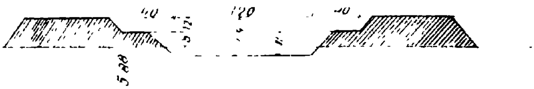
31. The maximum is not however so easily fixed. It must in the first place vary with the nature of the soil of the bed. A stony bed will stand a very considerable velocity, while a sandy bed will be disturbed if the velocity exceeds 3 feet per second. Again, if navigation requirements are to be considered, the maximum velocity at which a boat can be navigated against the current at a profit is evidently a very intricate problem, depending on such varying data as the moving power employed, whether steam, animals, or men, the description of boat, value of the cargo, &c. And without such a calculation for any particular locality, it is evidently impossible to determine whether it is worth while to undergo a heavy additional expense in reducing the slope (and, consequently, the velocity) of an irrigating canal in order to fit it better for navigation purposes If the saving thus effected on the total traffic annually conveyed would defray the interest of the increased capital required for the proposed reduction of slope, then it would doubtless be desirable to make that reduction, looking at the question from that point of view only. But there is a limit to the reduction of slope beyond a certain minimum, as explained above, owing to the paramount necessity of preventing the deposit of silt in the canal channel, and though 6 inches per mile has been given as the minimum limit which would not under ordinary circumstances interfere seriously with navigation, still it must depend of course on the fall of the country and the

CROSS SECTION,—GANGES CANAL.

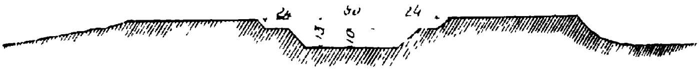
From Myapoor to the Ranipoor Torrent



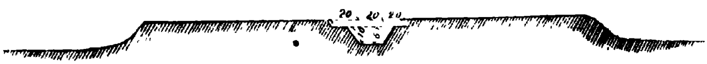
Section of Canal at Moradnuggur



Section at the 160th Mile



Section near the tail



nature of the soil, and so difficult is it often found to combine the requirements of the two purposes, irrigation and navigation, that it has been seriously proposed to provide for the latter by separate still water channels, made alongside the running canal itself.

32. In some experiments made on the Ganges Canal, it was found, that at a velocity of 3·76 feet per second, the water just ceased to cut *away the bank, and slightly deposited silt. With the ordinary soil of the plains of the N. W. Provinces, which is a light friable clay, and taking everything into consideration, perhaps 3 feet per second may be taken as a safe maximum velocity for these canals.*

The upper part of the Baree Doab Canal has a fall of 4·2 feet per mile over a bed of shingle and clay, but navigation at that point was not required.

The Ganges Canal starts with a fall of 2 feet per mile, which soon diminishes to 1·25 feet, and this latter may be said to be its 'ruling gradient.' With a depth of water not exceeding 5 feet, this gives a very manageable velocity, both as regards the safety of the works and the navigation *down*-stream. For *up*-stream navigation it would be advantageous to reduce it. But when 6, 7, or 8 feet of water are thrown into this canal, the velocity due to the above fall is doubtless too high.

In the Sutlej Canal project, Major Crofton has fixed upon $2\frac{1}{3}$ feet as his minimum depth of water at full supply, and has arranged his declivities of bed so that the calculated mean velocity of current shall in no case much exceed 3 feet per second.

For the Soane Canals, the velocity has also been fixed at about 3 feet per second (2 miles an hour), the side slopes being $1\frac{1}{2}$ to 1, and a bottom width equal to the depth plus one, squared, in feet.

33. The following Memo. on this important subject, from Major Crofton's report on the Ganges Canal, will be found very valuable:—

Velocities of current.—In a portion of the channel of the Eastern Jumna Canal lying in the old bed of the Muskurra torrent, where the current seemed perfectly adjusted to a *light sandy soil*, Major Brownlow, the Superintendent of the Canal, found the velocities of the surface to be from 2·38 to 2·28 feet per second, or mean velocities (multiplying by 0·81), 1·928 to 1·847 per second.

In the lower district of the same canal, near Birote and Deola, the maximum surface velocities with a full supply were found to be 2·817 and 2·507 feet per second, or mean velocity of 2·282 and 2·03 feet per second. Silt is constantly being deposited here; the soil is similar to that below Sirdhanna on the Ganges Canal.

About 1000 feet below the Ghoona Falls, on the same canal, in *very* sandy soil, with nearly a full supply of water, I found the maximum surface velocity to be 3·077 feet per second, or mean velocity 2·492 feet per second ; no erosion from bed or banks, except when a supply, much in excess of the maximum allowed, is passing down.

Below the Nyashahur bridge on the same canal, where the soil is very similar to that between the Myapoor and Kunkhul bridges on the Ganges Canal clay, shingle, *and small boulders, Lieutenant Moncrieff, R.E., the Superintendent, found the mean* surface velocity to be *6·751 feet per second, or the mean velocity about 5·468 per* second.

The same officer observed the surface velocity at some distance below the Yarpoor Falls in the new centre division channel of the Eastern Jumna Canal, and obtained a mean of 3·957 feet per second, or about 3·205 feet per second mean velocity through entire section. The soil here is light and sandy, and the channel has been both widened and deepened by the current

In one of the rajbuhas (or main water-courses) of the same canal, I found weeds growing in the bed and on the sides with a maximum surface velocity of 2·12 feet per second, or mean velocity (V) of about 1·717 feet per second ; the soil is sandy with a fair admixture of clay ; silt accumulates to a troublesome extent.

In another rajbuha in the same neighbourhood, I found a surface velocity of 2·38 feet per second, or mean about 1·927 feet. Silt deposits here, but no weeds appear to grow.

In the Mahmoodpoor left bank rajbuha of the Ganges Canal, I found grass and weeds growing in the channel with a maximum surface velocity of 1·724 feet per second, or mean of 1·396 feet.

In the Buhadoorabad Lock Channel, Ganges Canal, weeds appear to grow wherever the maximum surface velocity is 2·38 feet (or mean velocity 1·928 feet per second or under), soil generally light and sandy.

On the Ganges Canal I found velocities as follow —Below the Roorkee bridge on the main canal, where the deepened bed is covered with silt, and erosion from the sides has ceased, the mean velocity in the entire section, with a supply less than the present maximum on the Roorkee gauge by 2 inches, was 2·92 feet per second ; the soil sandy with a tolerable admixture of clay.

In the widened channel at the Toghulpoor sand hills, mile 36, the mean velocity, with full supply now allowed to pass down, obtained by calculation from the area of the water section and the discharge observed below Roorkee (deducting expenditure *en route*) was 2·532 feet per second.

In the embanked channel across the Solani valley, with a supply 2 inches under the present maximum on the Roorkee gauge, the mean velocity, obtained by calculation from the area of water section there and the observed discharge through the masonry aqueduct, was 3·04 feet per second. The deepest portions of the channelling out here have been silted up.

At the 50th mile, main line, below the Jaolee Falls, with (present) full supply in the canal, the observed mean velocity was 3·059 feet per second. Erosion from the banks has ceased here ; silt on the deepened bed, soil sandy.

Above Newarree bridge, 94th mile, in a stiff clay soil with full supply in, the observed mean velocity was 4·117 feet per second ; erosion trifling here ; no silt deposit.

34. *Observations communicated by Colonel Dyas, R.E., Director of Canals, Punjab.*—On the Hansi branch of the Western Jumna Canals, silt was deposited with mean velocities of from 2· to 2·25 feet per second. The deposition of the silt, however, obviously depends on the quantity and specific gravity of the matter held in suspension by the water coming from above, and the ratio of the current velocities at different points along the channel.

He states, from observations on the channels of the Baree Doab Canal, that in *sandy soil "2·7 feet per second appears to be the highest mean velocity for non-cutting as a general rule, for there are soft places where the bed will go* with almost any velocity; but those sorts of places can be protected." Again, "bad places might be scoured out with a mean velocity of 2·5 feet per second, but better soil would be deposited in place of the bad with a slightly smaller velocity than 2·5 feet; and as the supply is not always full, there would be no fear of not getting that slightly smaller velocity very frequently. The good stuff thus deposited would not be moved again by any velocity which did not exceed 2·5 feet per second.

In "Neville's Hydraulics," 0·83 or 1·17 feet per second are mentioned as the lowest mean velocities which will prevent the growth of weeds. This, however, will vary with the nature of the soil; vegetation also is much more rapid and vigorous in a tropical climate than where Mr. Neville made his observations.

In Capt. Humphrey's and Lieutenant Abbot's reports on the Mississippi, 1860, it is mentioned that the alluvial soil near the mouth of the river cannot resist a mean velocity of 3 feet per second; and that in the Bayou La Fourche, the last of its outlets, which resembles an artificial channel in the regularity of its section and general direction, and the absence of eddies, &c., in the stream, the mean velocity *does not exceed* 3 feet per second, and the banks are not abraded to any preceptible extent.

35. From the foregoing and other observations, and taking into consideration that the higher the velocity the less the works will cost, I think the following may be taken as safe mean velocities with maximum supply in the Ganges Canal channels.

1. In the Ganges valley above Roorkee, 3 feet ser second.
2. In the sandy tract generally between Roorkee and Sirdhanna, 2·7 feet per second.
3. In very light sand, such as that met with at the Toghulpoor sand hills, not higher that 2·5 feet per second.
4. And for the channels south of Sirdhanna, 3·0 feet per second.

On the branches, the same data to be assumed according to similarity of the soil.

There are soils, as Colonel Dyas has noted, such as light quicksand, which will not stand velocities of even 1 foot or 1½ feet per second, but these are never found to any great extent in one place: erosion there can only have a local influence, and such places can be protected at a trifling expense. It is channeling out on long lines which is to be feared.

36. From the above considerations, therefore, we can now determine the section of the canal channel by the help of proper mathematical formulæ.

Let D = the discharge at any point in cubic feet, A the area of

the channel section in square feet, and V the mean velocity, at that point in feet per second, then of course $D = AV$.

Now to find V, many formulæ have been given by Dubuat, Neville, and other authorities on hydraulics; some of which are very elaborate. Major Crofton uses (from Neville) $V = C\sqrt{\frac{d}{s}}$, d being the hydraulic mean depth,* s the denominator of the fraction denoting declivity of bed, the numerator being unity, and C a co-efficient, which he takes at 90 for velocities up to 4 feet per second, and 93 for high velocities, such as those of hill torrents, &c.

Dwyer's formula $V = 92\sqrt{2ds}$, d being the same as above, and s the slope of the bed in feet per mile, is recommended as simple and sufficiently correct for all ordinary cases of canal discharges.

37. In canals actually running, the velocities may be also determined by direct observation, as in the case of a river.

The observations for discharge of the Ganges Canal channels taken for the purposes of Major Crofton's report were obtained as follows:—

Two cross sections of the stream were taken at a uniform distance apart of 200 feet, the depth of water being measured at every 10 feet or less long the width of each section.

The velocities were obtained by noting the times of transit, at several points in the width of the stream, of floats from the upper to the lower section, these floats were made of painted deal rods about an inch square, loaded at one end so as to float nearly vertically and pass as close to the bed of the channel as possible without touching, their upper ends projecting a few inches above the water's surface. They were found in every case to float in a line closely parallel to the thread of the current. A very near approximation, it is evident, was thus obtained to the mean velocity in the vertical plane traversed by each. A correction for the small height of the end of the float above the bed was applied to each velocity before using them for the calculations of discharge, viz.—

C (or multiplier of velocity) $= 1 - 0{\cdot}116 \left\{\left(\frac{D - D_1}{D}\right)^{\frac{1}{2}} - 0{\cdot}1\right\}$

where

D = depth of water.

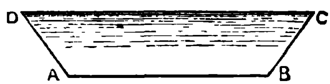
D_1 = length of rod immersed.

* Found by dividing the area of the channel section below the water line by the water contour (*i. e.*, the length of the bottom and sides of the section).

This was given in the report on the Mississippi by Captain Humphreys and Lieutenant Abbot, as obtained by Mr. Francis in his experiments at the Lowell Water-works, where velocities of current were observed in a similar manner to the above.

Velocities were observed on the Ganges Canal and elsewhere, also by a current meter of similar construction to that known as Woltmann's hydrometer, as well as by surface floats, but no method yet tried seems so satisfactory as that of the floating rods. The declivity of the water's surface was also in most cases observed for the purpose of comparison and obtaining reliable co-efficients for calculation.

38. To illustrate the foregoing, let us suppose that in the instance above given at para. 27, 4000 cubic feet were available as the minimum discharge, and that we determined to make our channel accordingly. We will fix on a fall of 1·5 feet per mile as the ruling slope, and excavate the channel with side slopes of 45°; then to find the necessary bottom width, AB, of the channel at the head; let the depth be to the width as 1 : 15 and call the depth x, so that $AB = 15x$, then $CD = 17x$, and the area of the section $= 16x^2$,



also as $AD = BC = \sqrt{2x^2}$, the wet contour $15x + 2x\sqrt{2}$, and the hydraulic mean depth $= d = \frac{16x^2}{15 + 2\sqrt{2}}$; and from Dwyer's formula,

$$V = \cdot 92\sqrt{2ds} = \cdot 92\sqrt{3d} = \cdot 92\sqrt{\frac{48x^2}{15 + 2\sqrt{2}}} = 1\cdot 5\sqrt{x},$$ and discharge $= D = 4{,}000 = 16x^2 \times 1\cdot 5\sqrt{x} = 24\sqrt{x^5}$; hence $\sqrt{x^5} = 166\cdot 67$, and $x = 7\cdot 74$, therefore $15x$ the bottom width $= 116$ feet. Or, we may, assume a value for x, and by trials approximate to the real value. Or, the depth of digging may be determined for us by our levels, which would also determine the bottom width, if it is to be 15 times the depth. And if these dimensions would not suffice for the required discharge, we should have to alter the ratio or else increase the slope of the bed.

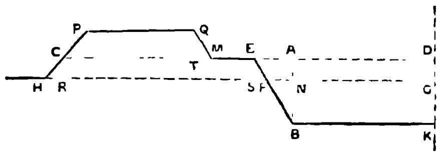
39. The section of the water channel and slope of the bed being thus determined, it is evident that the surface of the water may either be *within soil*, (as it is termed,) that is below the natural surface of the ground, or above soil, when it will have to be retained by artificial

embankments. If, not merely the surface level, but the whole body of water is above soil, the embankments must of course be very massive and may require to be puddled to render them water-tight. In the great Solani embankment, the water is retained within a solid masonry revetment on each side, backed up by an earthen bank averaging 16 feet high and 40 feet thick.

Although the water being thus raised above soil greatly increases the facility of irrigation by its command of level, it is evident that the construction of such embankments involves great expense, and that if any breach occurs the damage done will be very great.

40. The most favorable conditions are obviously when the canal water *is partly within and partly above soil, so that the earth excavated from the channel just suffices to build up the banks, while there is sufficient* command of level for all irrigating purposes; and the nearer this can be approximated to, the more perfect will the canal be. The following would be such a section:—

Let $2a$ = width of canal at foot B.
d = depth of canal AB.
x = required depth of digging.
Let A = area of bank above EC,
B = " canal be below DE,



Then whatever be the position of the natural surface, A and B are constants.

What we wish is to determine the depth BN so that the area BFGK shall = EFHPQ.

i. e., $B - EFGD = A + EFHC$

i. e., $B - \frac{ED + FG}{2} \times (d - x) = A + \frac{EC + HF}{2} \times (d - x)$

i. e., $\frac{d - x}{2} \left\{ (ED + FG) + (EC + HF) \right\} = B - A$ .. .. (1)

Let EC = h, let a = inclination of EB, β = inclination of HP. Then HR = CR $\cot \beta = (d - x) \cot \beta$, SF $= (d - x) \cot a$. And HF $= h + (d - x) (\cot a + \cot \beta)$ $\therefore$ EC + FH $= 2h + (d - x)(\cot a + \cot \beta)$.

Now $\left.\begin{array}{l} ED = AD + AE = a + d \cot a \\ FG = HG + FH = a + x \cot a \end{array}\right\} \therefore ED + FG = 2a + (d + x) \cot a.$

Hence, substituting in (1)

$$\frac{d-x}{2} \left\{ 2a + (d + x) \cot a + 2h + (d-x)(\cot a + \cot \beta) \right\} = B-A.$$

$$\frac{d-x}{2} \left\{ 2a + 2d \cot a + 2h + d \cot \beta - x \cot \beta \right\} = B - A \; ; ad - ax + d^2$$

$$\cot a - dx \cot a + hd - hx + \frac{d^2}{2} \cot \beta - dx \cot \beta + \frac{x^2}{2} \cot \beta = B - A \frac{x^2}{2}$$

$\cot \beta - x\,(a + d \cot a + h + d \cot \beta) = \mathrm{B} - \mathrm{A} - d\,(a + h) - d^2 \cot a - \frac{d}{2}$ $\cot \beta$.

From which equation we can find x.

Take an example, let $a = \beta = 45^\circ$.

Then $\cot a = \cot \beta = 1$.

Let $a = 50$, $d = 8$ feet, $h = 40$. PQ $= 25$ feet, QT $=$ TM 6.

$\therefore$ CM $= 37$. Then $\mathrm{B} = ad + \frac{d^2}{2} = 432$. $\mathrm{A} = \frac{25 + 37}{2} \times 6 = 186$.

$\therefore$ Equation becomes $\frac{x^2}{2} - x\,(106) = 432 - 186 - 8 \times 90 - 64 - 32 = 564 .\ x^2$ $- 212x = - 1148$, whence $x = 5\cdot 6$.

For sanitary reasons it may be desirable to keep the water as a general rule within soil, but the effect of this will be to increase greatly *the cost of the canal—and if, as is often the case, a sandy stratum under-lies the superficial clay, it is very undersirable to dig down to the* former as much water may thus be wasted by leakage and absorption, and large swamps formed which will require to be drained.

41. *Alignment of the Canal.*—The steps to be taken in fixing the line of the projected canal and in marking it out when approved of, will be similar to those described in the Section on ROADS. The gradients have to be duly considered in both cases, though much more carefully, as we have seen in the former. The requirements of the different towns and villages, which, in the case of a road have to be considered with reference to traffic, will have chiefly to be viewed in regard to irrigation, and secondarily only for traffic in the case of a canal.

The *obstacles* to be avoided, whether mountain torrents, swamps, hills, &c., are much the same, and the more elaborate methods of overcoming them required for canals, will be described further on.

42. The following instructions drawn up by Major Crofton, R.E., for the Punjab Irrigation Department, on taking levels for a canal project, and on subsequently laying out the line, will be found generally applicable :—

Trial Levelling and Surveying.—In addition to the levels of the country surface, a rough survey or reconnaissance is required, which should give information on the following points, viz.:—Approximate sites of villages or towns, lines of drainage, roads, railways, old water-courses, canal channels (main or rajbuhas), edges of high ("bangur") land, remarkable buildings, wells, nature of soils, crops, trees, &c.; position of stone or kunkur quarries, &c.

The places between which roads run, and their bearings (if regularly lined out), should be noted; if on embankment, the level of the top surface should be taken.

The bearings of regularly lined out canal channels or irrigation cuts, and the levels of their beds at points of crossing, with cross sections at right angles to the direction of each, showing level of full supply, are required.

The level of the lowest point in the beds of nullahs where crossed; with sections at right angles to their courses, showing level of highest known flood, and date of its occurrence if ascertainable; the level of surface of water in rivers (noting date of observation); depth of water on lowest point of bed (if obtainable), and level of ordinary and highest known flood; levels of floors of tanks and lowest points of large jheels should be observed and connected with the line of levels. The sites of such sections taken off the line should invariably be connected with the traverse.

The water-way of all bridges or culverts met with on or near the line of level should be measured: and the levels of their floors or plinths of abutments, or the bed under the arches if there be no flooring, with highest flood mark, carefully noted.

Wherever a well is met with or used as a bench-mark, the level of the surface of the water should be noted; the depth below the bench-mark can be measured with sufficient accuracy by the chain. If water is being drawn from the well, the surface will in general be abnormally low, in which case the height at which it usually stands when not in use should if possible be ascertained. The quality of the water, whether sweet or brackish, should also be noted.

These observations of the surface level of the springs should never be omitted when opportunity offers; it is a point of considerable importance.

The color and description of the soils, whether sandy, clayey, &c., the presence of the white or brown efflorescence known as "reh" or "kullur" should be noted.

43. A complete delineation of the drainage lines of the country being one of the primary objects of the survey, too great care cannot be taken in ascertaining their positions. They may be divided (excluding the large rivers) into two classes; the first easily recognizable by their

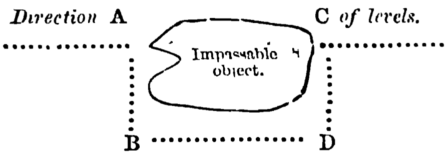
size; well defined channels running in valleys at some depth below the general level of the country adjoining. Into these and the rivers, innumerable channels of the second class discharge themselves, the exact positions of which are not always to be detected by the level alone. They usually rise in jheels lying close to the water-shed, and their courses are marked by a series of jheels connected by intermediate low lands; a black clayey soil "reh," rank grass, and crops requiring frequent *irrigation, such as sugar-cane, cotton, &c., generally mark the places where water has lain, or over which it flows in considerable quantity. No land of this description should be passed over without* enquiry as to whether it is flooded during rain, and from what direction the water comes and whither it runs off. "Reh," if contained in the soil, always rises to the surface where water has lain for any time, and appears in greatest quantity during the cold season.

Large towns or villages will almost invariably be found situated close to lines of drainage, or low ground where water collects after rain.

Sand hills, or very sandy soil, generally mark a water-shed on the "bangur."

Where a nullah or drainage line is crossed, and the level of the lowest point of the bed is observed, great care should be taken to ascertain whether this point is on the general level of the bed; if otherwise, the difference above or below should be measured and noted.

44. Where an impassable object lies directly in the line of direction of the levels, it should be passed thus :—



that is, wherever it is necessary to diverge for a short distance from the given line, it should be rejoined as soon as the obstacle is passed. In plotting the *section*, the points A and B, and C and D should appear identical.

Bench-marks should be established at intervals of about 3 miles in *general*, and one close to every large nullah or line of drainage, as well as at the ends of each cross section or line of levels. Existing buildings to be preferred for the purpose.

All Canal, Road, Railway, Great Trigonometrical Survey, or other bench-marks met with *en route* should be connected with the line of levels.

45. The error or difference in any circle of levels ought not to exceed 1 foot per hundred miles traversed. *Small* errors arising from incorrect reading of the staff, not holding it vertically, high wind, and such like, are inseparable from all levelling, but these will not be found to *accumulate* if the work be carefully done. A tendency, however, has long been observed, though as yet unaccounted for, to a small cumulative error in the direction of the levels; but this is not found to affect practical operations materially. Where great accuracy is required, such as in the proof levels of a canal channel, it is advisable to level twice over the same stations with the same instrument, the second level being carried in the reversed direction to the first; the mean reduced level of each station will be as nearly accurate as it is possible to obtain it.

46. For the purpose of determining water-sheds, on or near to which it is an object to carry irrigating channels, in a generally level country such as we have to deal with, cross sections at intervals, perpendicular to the snpposed water-shed, or line running centrically between the drainage lines on either side of the water-shed, will be found most advantageous in economizing time and labor. No rule can be laid down for the distance between any two successive cross sections; it must be regulated by the features of the country. For the general alignment of the main channels between two large rivers, the interval should not exceed 10 miles. For the actual lining out, and for the minor channels the interval probably should not exceed five miles, or possibly less, though in most cases, I believe, it will be found to answer the purpose better to map out the drainage of the country minutely than to take cross sections at smaller intervals than five miles.

These cross sections should be connected by longitudinal lines between their extremities to test the accuracy of the work; the latter, unless intended for some other special purpose, may be carried on the most direct lines between the points to be connected.

Wherever drainages are met with, enquiries should be made as to their courses, both above and below the lines of levels, names of villages near which they pass, &c.; by thus observing them in each successive line of cross section, a very complete plan of the drainage of the coun-

try is obtainable, as well as a connected series of levels along the beds of the outfalls.

Similar information to that detailed above should be obtained with all levelling or surveying for rajbuhas, drainage projects, or any other work connected with irrigation.

47. In levelling for the longitudinal section of a river, the line should follow generally the main water channel, the stations being invariably on the bank or dry ground near the edge of the stream. The level of the surface of the water at intervals (noting date) of ordinary floods and highest known flood; the position of the top and foot of rapids (if any) and level of surface of water at each point to be noted. The depth of water to be measured in the deepest part of the channel where the surface level has been observed. Cross sections at right angles to the direction of the river should be taken at intervals and connected with the series of levels showing the bed, surface of water, level of ordinary and highest known flood. The survey should show all minor channels and affluents (if any) and as nearly as possible the extent of land under water in high floods. The nature of the bed, whether of boulders, sand, clay &c., should be carefully noted.

48. A prismatic compass held in the hand will be found very useful in filling in details off the line of the series of levels. If the variation of the needle is not identical with that of the level employed, the bearings should be reduced before entering in the field-book to the meridian of the latter. Most of the side measurements, where great accuracy is not required, may be made by pacing. Two and a half or three feet paces will be found most convenient as admitting of easy reduction to feet.

The scale generally for protraction of levels should be 1 mile to 1 inch. For the sections, the horizontal scale same as for the protraction; the vertical, 100 times the horizontal. Larger or smaller scales may be necessary for special purposes; but *always* measures or aliquot parts of the one-mile-to-the-inch scale.

On every protraction of levels, besides the heading, the following must never be omitted. Date of the survey, name of the surveyor, scale and meridian line; the numbers attached to the several stations on the section to be identical with those on the protraction.

All details noted in the field-book should be transferred to the protrac-

tion or section; a sketch and a short description of each bench-mark to be entered on the back or margin of the sheet in which its position is shown. The information is thus more accessible than if old field-books have to be searched for it.

If a map is to be compiled from levels or surveys taken with more than one instrument, it will be found best to protract the work done *with each instrument on separate sheets, to be subsequently transferred on to the map.*

49. *Survey and lining out Canal Channels.—Preliminary Survey.*— After the position of the line, which may generally be assumed as the water-shed, has been approximately determined by names of the cross sections, or otherwise, an accurate traverse with the theodolite should be taken over it, including a survey of the ground for about half a mile in general, or further, if deemed necessary, on each side, which should give information on the following points, viz.: features of the country, if irregular; nullahs, lines of drainage and jheels, wherever met with; sand hills or ridges; towns and villages, wells, buildings, whether of masonry or mud; roads, whether regularly lined out or merely cart tracks—if the former, the bearings should be taken; places between which they run (whether tracks or made roads), and whether they are lines of traffic or merely village communications, should be carefully ascertained (this is useful afterwards in determining the sites of bridges): village boundaries, &c.; such minutiæ as the boundaries of fields are unnecessary, those of gardens may be useful; in fact, everything which is likely to be of assistance in determining the precise line, or which it would be advisable to avoid if possible. A survey of this nature, carefully taken, will generally admit of choosing a line which will not injure property or disturb existing rights in the least possible degree.

The accuracy of the traverse is the point to be chiefly looked to; the distance between the stations on it should be as long as possible; never, if practicable, less than a mile, as the probabilities of accuracy in observation are greater in the case of long than short sights, and the plotting, is easier as well as more likely to be accurate. The sights to the station poles should be taken as in ordinary traverse surveying, but should show the magnetic bearing of the lines, or their supplements; these should be checked by repeating the observation at each station, thus:—Clamp the upper plate on zero of the lower and fix on back pole; then turn upper

plate round to sight fore pole, noting the angle in the field-book; this angle should equal the difference of the magnetic bearings first observed. This will check the directions of the traverse lines. To check the distances between stations:—Fix on a well defined point some distance to one side, say a mile, and observe to it from every station from which it is visible. If the distances have been measured and plotted correctly, and *the bearings are accurate, the latter will all meet in one point on the* map.

The stations may be marked on the ground by large pegs, about three feet long, driven well in. If their future identification is an object, and there is a chance of the pegs being destroyed or removed, a ghurrah filled with charcoal, buried at some depth below the surface of the ground will give the means of finding their sites again with sufficient accuracy for all practical purposes. The surest way, however, is to note their distances and bearings from any easily recognized and premanent objects which are not likely to be disturbed, if such should be found sufficiently near for the purpose. It will be found most convenient to fix all stations on mounds or rising ground.

All bearings taken with the theodolite should be noted to the smallest portion of a degree its graduation will admit of; for, although they cannot be plotted nearer than to a minute, close observations are necessary to ensure accuracy in a long line of survey. Bearings should be taken to all well defined objects, such as spires of temples, &c., wherever visible; though possibly useless for the special purpose of the survey they may be of importance hereafter in giving the means of joining on other surveys to any of the traverse stations.

The angles on the side surveys may be taken with a good compass, prismatic, or of any other description available; the actual bearings, as shown by the instrument employed, being entered in the field-book, *i. e.*, no correction being made *in the field* for the variation of compasses (if any). Villages should be traversed round, so as to determine their outer limits, but no interior survey is required. These should be connected with points on the main line of traverse; the correctness of the junction line may be tested by observing from several points on it to some object in or near the village (such as a large tree, house, &c.), which has been well connected with the boundary survey of the village.

As the choice of a good line and the actual lining out on the ground

very much depends on the accuracy of a map, this should be placed beyond a doubt, if possible before the line is chosen and marked on it. The time occupied in taking check observations and measurements in the field will be well repaid by the facilities afforded to the subsequent work by a really accurate plan of the country.

It will be found convenient to have two descriptions of poles (jhundees) for setting up on stations to which observations are to be taken, one for use in windy weather, mounted with a flag; the other when the air is calm, with a small "moon" (made by covering a wooden hoop with calico) about 1½ feet diameter; as a flag when not flying free is scarcely more distinguishable at a distance than the bare pole. On the revenue *survey, poles painted in foot lengths,* white and black alternately, are *employed, which makes them visible at a far greater distance than the* common uncolored bamboos.

The position of the actual water-shed near the line of traverse should be carefully ascertained and noted on the map.

50. *Lining out.*—If the levels of the water-shed admit, the nearer the line of canal approximates to it the better: the interference with the surface drainage of the country being then the least possible. It should be laid down in straight lines as far as practicable; the fewer the curves the better; none, unless in special cases, of less radius than three miles or 15,000 feet, though curves of 5,000 feet radius on the Baree Doab Canal have been found to answer very well. It is of course a desideratum to avoid villages, buildings, and valuable property of all kinds if possible, and this can generally be effected without sacrificing the primary considerations which should guide the choice of a line, if the map be accurate and give sufficient detail.

Wherever the water-shed cannot be adhered to exactly, ground should be chosen from which the surface drainage can either be passed into the canal channel or turned off in some other direction; otherwise jheels and swamps will form after rain on its water-shed bank. It should be considered, however a standing rule, that no drainage water should enter the canal channels, large or small, unless it be *impossible* to dispose of it in any other way.

The centre line of the intended channel having been laid down on the map, and from it transferred to the ground, all boundaries, &c., can subsequently be demarcated from it. In laying down curves on the

map, the use of "French curves," or card board cut to the required shape, will be found to facilitate the process considerably.

The following is recommended as the least laborious method in the description of country with which we have to deal, of transferring the line on to the ground, and sufficiently accurate for all practical purposes.

First, for the straight portions. Find the approximate bearing of the line and measure off-sets to it from two survey stations, say two or three miles apart on the map. These off-sets measure off on the ground; two points are thus obtained in the required line, which may then be produced either way at pleasure.

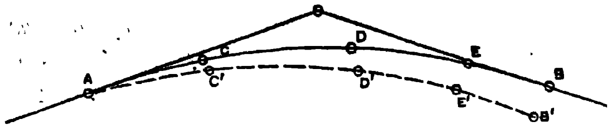
51. Where a curve is required, produce the tangents (obtained as above) *on the ground till they meet, marking their intersection as described for survey stations; the angle between them may then be observed, and their lengths found by calculation* for a curve of the radius previously determined on the map. Measure off these lengths from the intersection, marking the commencement and end of the curve thus obtained by large pegs. In cases where the intersection falls on ground from which the lines of tangents are not visible, the angle between them must be obtained from the map, and the lengths calculated therefrom. The points marking the termini of the curve being thus determined on the plan, they must be transferred to the ground lines by measurement from some points fixed by the survey.

In laying down the curve itself, it will be sufficient for all practical purposes to fix points at such intervals that the versed sine of the intercepted arc shall not exceed 0 25 foot, or thereabout. These points may be obtained by off-sets from the tangents where the maximum length of such off-sets does not exceed 30 to 35 feet; above this limit, it will be advisable to adopt the method of off-sets from chords. Calculate the number of chords of a constant length (1000 feet or 2000 feet answer best in practice), and the length of the remaining chord contained in the curve. Proceed to lay them down in the usual way with the theodolite, and commencing from one end of the tangent; if correctly done, the end of the last chord will fall on the peg marking the termination of the other tangent.

If there is some small difference on closing (and in a long curve this generally occurs in direction; seldom in length), correct thus—

Supposing A′ C′ D′ E′ B′ to be the line as laid down on first trial, and

A C D E B the correct one; the distance B B′ being measured, the

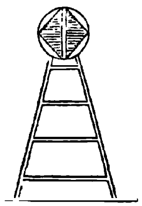


corrections for the other chord ends or distances E E′, D D′, C C′, may be found by assuming the space between the two curves to be a triangle, and the lines, E E′, &c., to be drawn parallel to the base B B′ : B B′ and *the lengths of the chords and the entire curve being known, the corrections are easily obtained; then returning over the curve, correct the positions of the pegs marking chord ends. If the difference in the length* of the curve is considerable, it will be advisable to go over the work altogether again; this, however, with careful work seldom happens.

Having thus fixed the ends of the chords, lay off the off-sets distant from each other not more than 200 feet, if on a curve of three miles radius or upwards; on curves of less radius the interval should not exceed 100 feet. These points may be marked by pegs about $1\frac{1}{2}$ foot long.

Chords of 2000 feet in length will answer for curves of 3 miles radius and upwards; for radii of 2 miles and 1 mile, 1000 feet chords.

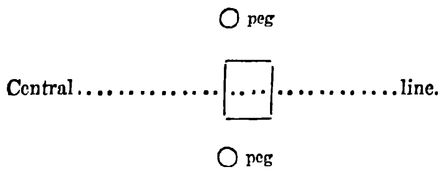
52. In laying down long straight lines it will be found advisable, and



in very uneven ground absolutely necessary, to use one or two signals of much greater height than the ordinary flag-staff. Such a signal may be made, as shown in the annexed sketch, by connecting two bamboos, say 40 to 50 feet long, in the form of a ladder, joined at top, and about 5 feet apart at bottom, by cross pieces at intervals; a " moon," formed with a wooden hoop strengthened with cross pieces and covered with calico, being fastened at top; the centre of this moon is then adjusted over the line by a plummet, and the whole is secured in its position by three guy ropes attached to large pegs.

Other methods of laying down curves may be necessary where the ground is much encumbered with obstacles; but for the description of country usually met with in the plains of Northern India, the method above described will, it is believed be found the simplest and most practical.

The ends of curves should be marked by a small cube of masonry sunk to the level of the ground, as it is difficult afterwards to find the exact positions, if some permanent mark be not made at the time of lining out bench-marks of masonry (one foot cube will answer) should be sunk to the level of the ground at intervals of 500 feet along the central line of canal, and numbered on top to denote the distance from the zero of longitudinal measurement. Those denoting even thousands of feet to be marked with integers; the intermediate ones thus "$\frac{1}{2}$." It will be found a great saving of time if the positions of these bench-marks be marked simultaneously with the lining out, and this may be done by *driving in two pegs thus :—*



Position of B. M.

On straight lines one chain only is necessary; on curves two should be employed; one in measuring distances along the chords, or tangents (as the case may be), for the off-sets, the other meanwhile following along the curve. By this means the nick can be cut and the bench-marks laid in immediately in the wake of the surveyor; and the sooner this can be done the better, for none but marks of masonry will long remain where people and cattle are constantly going to and fro. The bench-marks, however, should not be waited for to commence cutting the nick; this should be dug at once about half a foot deep; a long narrow cut is not easily effaced. The marking out and cutting the boundary nicks should follow that of the central line. If there is any fear of the bench-marks being injured by cattle, &c., cover them with a small mud pillar.

The chain for measuring distances along the central line should be exactly 100 feet long, and its length should be constantly checked, as this measurement must be as accurate as it is possible to make it.

The zero of longitudinal measurement for the central channel of a canal is the face of the up-stream head wall of the regulating bridge at the head. For the branches, or any minor channels, the same line on their respective regulating bridge heads.

The details of all curves, such as the angles between the tangents, length of tangents, number and length of chords, &c., reduced distances from zero of longitudinal measurement of extremities of curves, crossing points of roads, nullahs, &c., and all other items of information likely to be useful hereafter in the construction of the works, should be noted in the field book *on the spot*.

In aligning the minor irrigation channels, so great accuracy is unnecessary, as curves may be more frequent and of smaller radius; but the same care should be taken as in the case of the larger channels, to avoid as far as possible injury to existing property or disturbance of existing rights.

For producing straight lines on the ground, a theodolite is unnecessary; a good reconnoitring telescope will be found to answer the purpose perfectly.

53. In the actual construction of the line, the *Cuttings* will be laid out and made like road cuttings, but it is evident that the *Embankments* must be different, as they have to retain within them a large body of water. Their thickness must, therefore, be very great on both sides of the water channel, and they vary in mean width from 30 to 100 feet, according to depth of water. If leakage occurs they must have a wall of puddle or be otherwise rendered water-tight.

The method of constructing the cuttings and embankments has been sufficiently treated of in the Section EARTHWORK.

54. In the annexed Plate are some cross sections of the Ganges Canal, taken at different points along its course, showing the channel as originally excavated; and the following account of the method of excavating the most difficult portion of the line will be found interesting.

From the Puttri Superpassage to the Rutmoo River.—This is perhaps the most interesting line of work that has been excavated. The length is equal to 16,810 feet. On its course it passes through a ridge upon which the villages of Gurh and Saynibas are situated; and with the exception of the super-soil, to a depth of from 7½ to 20 feet, it is entirely excavated through earth impregnated with springs.

The work was tedious and very expensive; it required, moreover, the constant vigilance of an active supervisor, to see that what was done in one day, was not, by the action of the springs, undone the next. The spring-water, which is kept down by impervious superstrata, rises immediately it escapes from its bondage. At a nulla, which is intersected by the canal, water runs in a perennial stream. The difficulties of excavating this portion of the canal, may be comprehended by explaining

that the stream in question, naturally runs on a level of 8·18 feet above that of the canal bed. This nulla was merely an external exhibition of the spring level throughout the whole line of country now referred to.

After removing the super-soil, or that unconnected with springs, an escape was made near the above nulla. The distance from the Puttri to this nulla is 10,804 feet, so that, in making use of the escape, for the relief of spring-water during the excavations, a considerable slope was available. The direction of the spring current

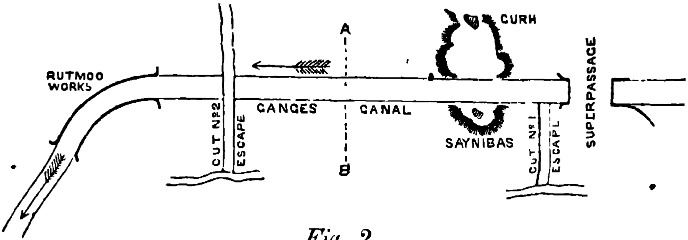
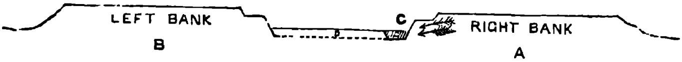


Fig. 2.



was from north to south, or from the high to the low land. The canal channel intersected this at right angles. The Executive Engineer's plan of operations will be best understood by diagrams showing the line in plan and section.

The true section of the canal in its full depth is represented by the dots. The way that this was reached will be understood by the shade C, *Fig* 2, which represents a ditch or cunette, in this case a catch-drain for the spring-water which flowed in the direction of the arrows. This cunette was carried along the whole line of excavation and terminated in the escape No 2. Both cunette and escape were maintained in a constant state of efficiency as regards the free run of water. By the interposition of cunette C, that portion of the canal channel at D, *Fig* 2, was excavated without trouble, as it was entirely cut off from its spring supply. The process was a very gradual one. As the depth of the cunette was increased, so did the portion D become relieved of its difficulties. It was an operation requiring especial care; and in a pecuniary point of view, the greatest attention to prevent the work of one day being obliterated by the action of springs during the night-time. The whole work was, however, completed satisfactorily.

55. The considerations which determine the site of the canal head have already been noticed. The canal should be made to *tail* into a river or nullah, into which the surplus water unexpended will be discharged, and in order to secure an efficient scour, it will be advisable slightly to increase the velocity at the end. A fall into the outfall nullah or river is generally the best way of effecting this. It should be understood however, that it will rarely, if ever, be expedient to keep up a permanent stream in the outfall, with the view of scouring out the canal, and it would obviously be no advantage to discharge muddy water

from the tail of a canal, or from an escape, if the same quantity of equally muddy water were admitted at the head. But in practice, owing to bursts of rain falling suddenly along portions of a long canal, and causing an excess of water where there may not be time or when it may not be considered desirable to reduce the supply entering the head of the canal, it is very necessary that there should be means of turning off the surplus.

56. The points at which *Branches* should be taken off from the main line, as well as the general course of these branches, will be fixed from a due consideration of the levels of the country and the extent of culturable land requiring irrigation. If the main canal has been carried on or close to the water-shed or backbone of the district, then the branches should be lined out as far as possible on the minor ridges which lie on both sides of the main ridge, the object in every case being to keep a sufficient command of level for surface irrigation. There is a further reason for carrying the canal channels on watersheds wherever possible, viz., to ensure, the minimum of interference with the country drainage, the importance of which will be explained further on. The size of the branch channels and slope of their beds will be dependent on the same principles as those already noted in the case of the main line, and the same remark applies to the *Rajbuhas* or distributing water-courses which are led off from the main and branch lines, and from which it is now the most approved practice to deliver the water for the actual irrigation, its further employment being left to the cultivators (*See* further on).

57. *Bridges* of communication are required wherever roads cross the canal, and for the general convenience of the country. On the Ganges Canal they were designed at about every three miles apart; and, when in the vicinity of large villages, are provided with *ghâts* or steps for convenience of bathing. Care should be taken to provide sufficient headway under the arches or openings for laden boats to pass easily when the canal has its full supply. On the Soane Canals, 13 feet are allowed for this purpose, and it is also desirable that the obstruction to the stream presented by the piers should be as small as possible; for this purpose it will generally be advisable to widen the canal slightly at these points so as to allow a *full* waterway for the stream through the bridge. Otherwise, expensive precautions have to be taken to secure

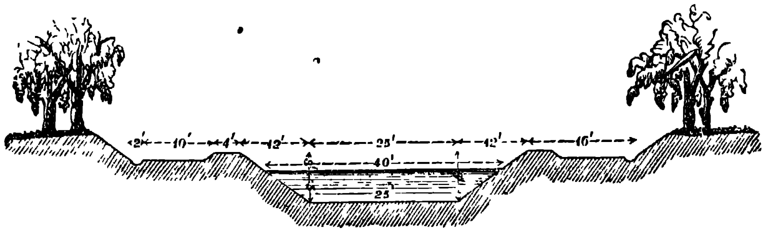
the foundations, and the increased velocity under the arches will render navigation dangerous or at least difficult.

58. A *Tow-path* should be provided on at least one side of the canal at a constant level of 1 to 2 feet above the water surface. It may be from 12 to 15 feet wide in earthern section, and not less than 6 feet under bridges; the tow-paths should be carried *under* the side arches of bridges, in no case through the abutments or wing-walls, the latter arrangement being an obstacle to free navigation.

59. A *Road* is also desirable on one side of the canal for convenience of inspection. It may be 20 feet wide and planted with trees. Tree *plantations* are also general along the canals of the N. W. Provinces, No trees should, however, be allowed within 30 feet of the water's edge. *as their proximity interferes with the stability of the embankments.*

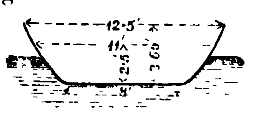
60. *Chokees or stations for the Engineers and Overseers employed* on the line are also provided at intervals, and are generally fixed at the site of the most important masonry works.

61. The following note on the dimensions proposed for channels and masonry works, of NAVIGATION CANALS in Upper India is by Major H. A. Brownlow, R.E., Superintending Engineer, Ganges Canal.



Proposed section of Channel.

The midship section of wooden boats in general use on these canals is given.



Length, 45 feet.
Top width, 12 5 feet } midship section.
Bottom width, 8·0 feet }

their draught will be 2·5 feet, when laden with 450 to 500 maunds, the usual burden.

Rankine gives as dimensions and proportion of channel, required to prevent any material increase of resistance to motion of boat, beyond what it would encounter in open water—

Least breadth at bottom = 2 × greatest breadth of boat.

Least depth of water 1·5 feet + greatest draught of boat.

Least area of water section = 6 × greatest midship section of boat.

Side slopes not less than 1 in 1·5.

The midship section, to water line, of the wooden boat, of which the dimensions are given above, may be taken as 25 superficial feet.

Area of water section of proposed channel = 162·5 superficial feet.

Depth of proposed channel = 2·5 + usual draught.

Bottom width = 2 × greatest breadth.

Side slopes of proposed channel, 1 in 1·5.

Mr. Kelly (whose opinion is most deserving of consideration) would prefer side slopes of 1 in 2, in order to admit of gravel or pitching being laid along the line of wash, for protection of slopes. Side slopes have been made 1 in 1·5, however, with the view of economising excavation and ground occupied by channel.

62. *Towing-paths.*—Towing-paths to be provided on each bank. To be 3 feet above surface of water except in very deep digging, where, to economise excavation, they should run 4 feet above water surface. To be 10 feet wide in the clear, with a slope of 1 in 20 to outside. An edging 4 feet wide at bottom, 2 feet wide at top, and 1 foot high, to run along crest of side slope of channel, and a shallow drain 2 feet wide, and 6 inches to 8 inches deep, along exterior edge of towing-path, when there is a spoil bank.

Spoil Bank and Plantations.—Spoil to be thrown with an interior slope of 1 in 1. Exterior to be sloped off like a glacis, and to be planted with trees. Mr. Kelly strongly advocates establishment of plantations on both banks of still water channels, along their whole lengths, as tending to check their obstruction by drift of sand, dust, &c. The proposal is a most excellent one, and is strongly recommended for adoption, where the value of land that would be occupied by them is not exceptionally high.

Embankments and Puddling in Sandy Soil.—All embankments to be formed and rammed in thin layers. Where the channel runs through porous sandy soil, bed and banks to be covered with a thin coating of puddle. This might be effected more cheaply after the opening of channel by boating pulverised clay to the requisite points and strewing it over the surface of the water.

63. *Waterway and Headway of Bridges.*—Waterway of bridges 16×5 feet; clear headway for boats, 16×10 feet; clear headway for towing-path on each side, 6×5 feet; $5\frac{1}{2} \times 4\frac{1}{2}$ feet (height) being required for passage of a pair of yoked bullocks. Section of bridge to be as shown in *Fig.* 1, *Plate* IV.

Locks.—Lock chambers to be 100 feet by 16 feet in the clear, *and to be on general plan given with the substitution of a second lock chamber for the side chamber constructed in the Ganges Canal* locks.

Stops Dams.—Channel to be divided by stop dams into reaches of two, or at the outside, three miles in length, so as to isolate a breach or any point where drainage may have broken in; also to enable any portion to be laid dry in case of repairs being required. These stop dams to be formed of 2 pairs of lock gates, shutting in opposite directions. Such a dam to be constructed also at junction with main canal to keep out silt, and guard against fluctuations of level.

Under Sluices.—Each reach of the channel beween any two stop dams to be provided with an escape outlet, by which it may be wholly emptied of water, for clearance or repairs if necessary.

Waste Weirs.—Also with a waste weir, to provide for discharge of any drainage that may accidently find its way into the channel.

Drainage—Arrangements to be made, however, for diverting, or passing under the channel, all drainage that may intersect the line.

64. CHANNEL WITH FLOW OF 2·5 FEET PER SECOND.—Where possible, however, the navigation channels to be designed so as to secure a velocity in them $2\frac{1}{2}$ feet per second.

Section of earthen channel to be as before.—Then assuming section given above, as minimum allowable (for reasons given), we have—Discharge of channel $= A \times V = (32{\cdot}5 \times 5) \times 2{\cdot}5 = 406{\cdot}25$ cubic feet per second, $S = \frac{90^2 \times R}{V^2} = 1296\ R = 1296 \times 3{\cdot}8 = 4924{\cdot}8$, giving a fall of 13 inches per mile, very nearly.

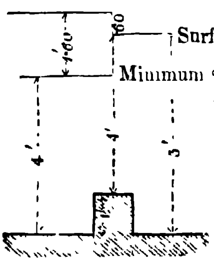
Waterway and Headway of Bridges.—16 feet long by 10 feet clear headway, to be allowed for boats; with a couple of towing-paths, clear headway of each 6 feet $\times$ 5 feet. *Fig.* 2.

Towing-paths.—Towing-paths to be as laid down above for still water channels.

Locks —Locks to be double, iwth a chamber in centre, similar to the side chamber in Ganges Canal Locks.

65. *Points off departure from, and junction with, Main Channel.*—Channel to be provided with regulating chambers, in form of locks, with level floorings, at points of departure from, and junction with, main channel. The surface level of canal is liable to fluctuations within the limits of $2\frac{1}{2}$ feet, and supposing surface level in navigation channel fixed about one foot above level of minimum supply which is exceptional, and short in duration) the navigation channel would during periods of minimum supply be discharging 282 feet per second, with a depth of 4 feet, and a mean velocity of $2\frac{1}{4}$ feet per second. But when the canal supply was at its highest, the navigation channel would be discharging 877 cubic *feet, with a depth of $6\frac{1}{2}$ feet and a mean velocity of $2\frac{3}{4}$ feet per second. This increase in depth would be very inconvenient. perhaps dangerous, and it would add considerably to the expense of bridges and earthwork* along the whole line of navigation channel, to provide properly for it. Again, the surface level of the navigation channel, at point of junction with canal, must be fixed on the level of full supply in the latter, otherwise a rise in the main channel would throw a back water up the navigation channel to an extent proportionate to its height, and silting up at the junction would inevitably follow the checking of velocity. Regulating chambers, at the head and tail of navigation channels, seem therefore absolutely necessary.

These chambers might be made, as suggested before, in the form of a lock chamber, 100 feet long by 16 feet wide in the clear. At the head of the navigation cut, with a low supply, or average supply, in the canal both gates of the chamber would be kept open. When the supply in the main channel rose to an inconvenient height, both gates would be closed, and the navigation cut would then be fed through a side inlet.



Surface level in navigation channel.

Minimum supply in canal.

$$D = c_d\, l.\, \sqrt{2gd_1}\,(d_2 + \tfrac{2}{3} d_1).$$

$$D = 406{\cdot}25 \quad C_d = 0{\cdot}628.$$

$$d_1 = 0{\cdot}60.\ d_2 = 4{\cdot}0.$$

$l = 24$ feet, very nearly.

The flooring of this inlet would be built about a foot above the canal bed, so as to keep out the water most highly charged with silt. It

Dimensions of Arch for still Water Channel.

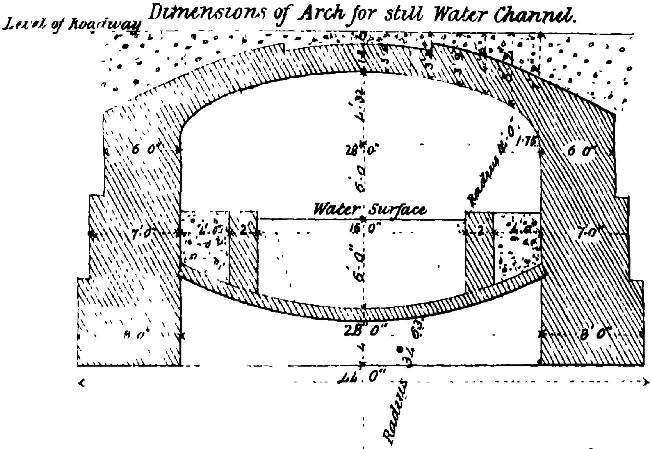
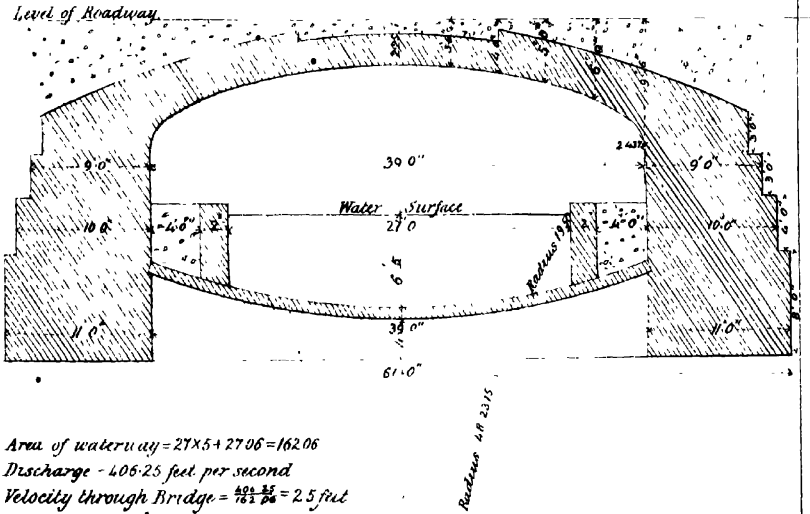
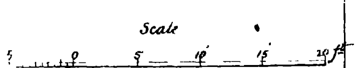


Fig 2

Dimensions of Arch with velocity of 2 5 feet in Channel



Area of waterway = 27×5 + 27 06 = 162 06
Discharge - 406·25 feet per second
Velocity through Bridge = $\frac{406\ 25}{162\ 06}$ = 2 5 feet

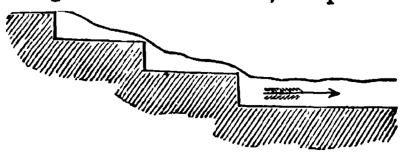


would have to consist of about four bays of 6 feet width each, the bays being closed by sleepers dropped into grooves as occasion required; thus at the tail of navigation cut, when the water in canal fell so much below the full supply level as to cause an inconvenient increase of velocity in the channel, the lock gates would be closed and the velocity would be duly regulated by increasing or reducing the discharge through a side chamber.

CHAPTER IV.

FALLS—RAPIDS—LOCKS.

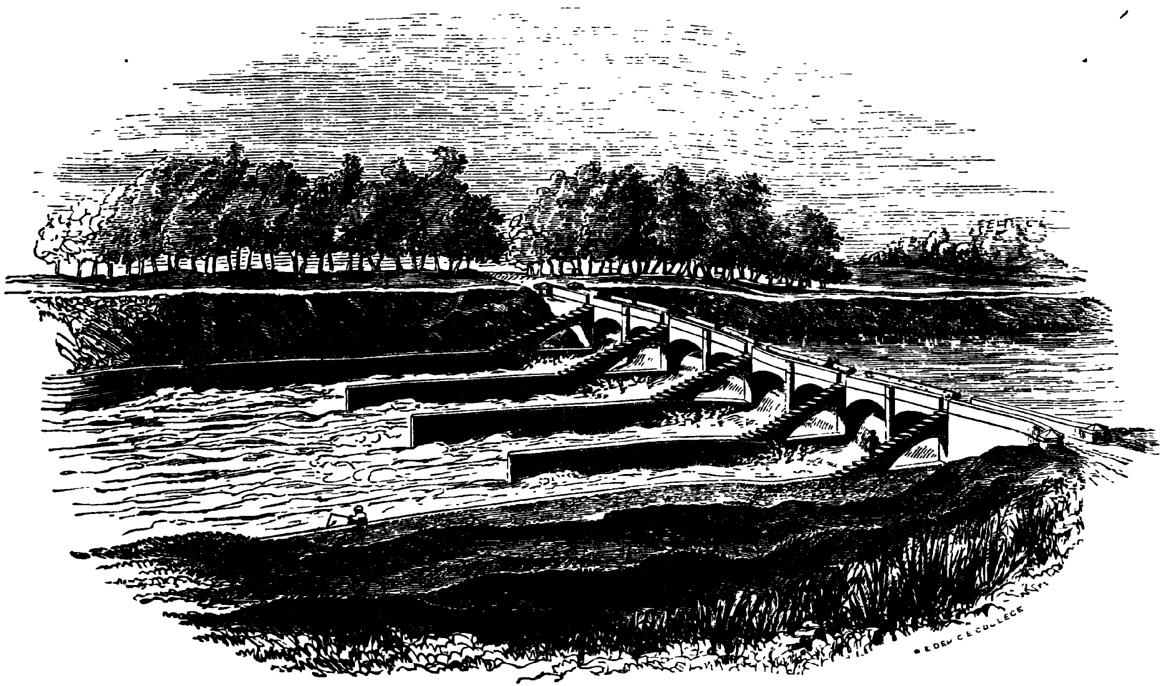
66. So long as the slope which we determine to give to the bed of our canal from the considerations above stated, is the same as the natural *fall of the country through which the canal is excavated, the level of its bed will of course remain at a uniform depth below the surface of the ground.* But although this can generally be managed in the flat plains of these Doabs throughout the greater portion of their length, yet in the *upper* portion of the canal, the slope of the ground is very much greater than that which it would be proper to give to the canal bed, and peculiar arrangements have to be made to compensate for this difference of slope. The annexed diagram will show how this excess of fall has to be overcome; viz., by



laying out the canal bed in a series of *steps*, so as to deep it at a tolerably uniform level below the surface of the country, until the flat country is reached where the slope is the same as that proper for the canal.

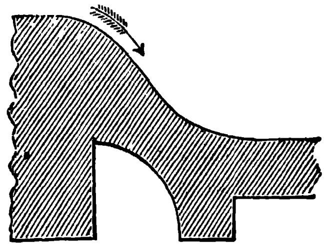
The points where the bed is let down from a higher to a lower step are called *Falls;* and their shape and construction are questions requiring much thought and consideration. Their location should evidently, from the diagram, be near the places where the canal bed, if continued without a break, would have to be carried in embankment above the surface of the country; their *exact* position is generally made to coincide with the requirements of a bridge or some other masonry work, such as are described hereafter, for the sake of economy of construction, or on other grounds which need not be entered upon here.

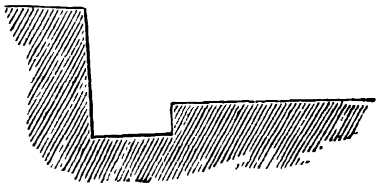
67. It is evident that the fall must be of some more durable material than earth to resist the action of the water over the step, and masonry is



ASUFNUGGUR FALLS.—GANGES CANAL.

therefore employed. The bed of the canal has also to be protected by a *masonry flooring from the plunging action of the water, and banks must also be revetted for a considerable distance below to prevent their being* cut away. The exact shape of the *fall itself* is a point on which there is much difference of opinion. Ogee falls of this shape were employed by Sir P. Cautley, on the Ganges Canal, with the idea of delivering the water at the foot of the fall as quietly as possible. On the Baree Doab Canal vertical falls are used, the water being received at the bottom into a cistern sunk below the level of the flooring, which thus forms an elastic cushion, as it were to receive the shock instead of opposing a dead resistance to its force; while the accelerated velocity of the falling water in a forward direction is thus also checked. The action of the water is still further lessened by making it play over a wooden grating, by which it is divided into a number of filaments or threads, as if it were discharged through the teeth of a comb.





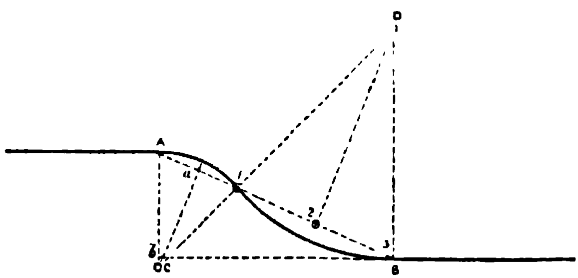
68. The very dangerous scouring and cutting action of a large body of water falling over a height of even a few feet can be readily understood. The greater the height of the falls and the depth of water, the more violent of course will be the action; those on the Ganges Canal are not higher than 8 feet, but with 6 feet or more of water going over, the action is most severe, and nothing but the very best masonry is capable of resisting it. If stone can be obtained, it should always be used; if not, none but the hardest bricks must be employed, laid on an unyielding foundation with fine mortar joints; the banks must be revetted with masonry for a considerable distance down-stream, and the bed of the canal protected by a solid masonry flooring, the tail of which is defended by a row of sheet piling. The fall should be divided into distinct chambers, which can be laid dry one by one for the sake of repairs without stopping the canal. On the Ganges Canal the masonry flooring is continued to the end of the chamber, beyond which, crib-work of dry boulders is employed as far as the end of the revetment walls.

The revetment walls on this canal were inclined slightly inwards and terminated by curved walls (*see* Plate), with a view of holding up the water on the flooring, and thus saving the latter from the effects of any scour. *But the result has been, serious cutting of the banks below the* curved ends, and the curved walls are now being removed in consequence. On the Belra Falls on this canal, the revetment walls were carried straight on instead of being inclined inwards, and then terminated by curves forming a basin; and these have answered better, though it is said the soil is there much stronger.

69. The following is a description of one of the Ogee* falls on the Ganges Canal, drawings of which are given in the Plate:—

The fall consists of a bridge (of eight bays of 25 feet in width each), which crosses the canal on the upper levels; to the tail of this bridge the ogees are attached, delivering the water into four chambers of $54\frac{1}{2}$ feet each in width, every alternate bridge-pier being prolonged on its down-stream face, so as to divide the space which is occupied by the lower floorings into four compartments; in advance of the three dividing walls, which are carried to a distance of 84 feet from the down-stream face of the bridge, there is an open space of masonry flooring, which is protected by an advanced area of box-work, or heavy material filled into boxes or crates, and covered with sleepers, so as to retain the material in position. Additional defences are given to these floorings by lines of sheet piling. The flanks of the chambers below the descent are protected

* The curve of the Ogee is thus described.—



$bB = \frac{5Ab}{2}$

$A1 = AB$

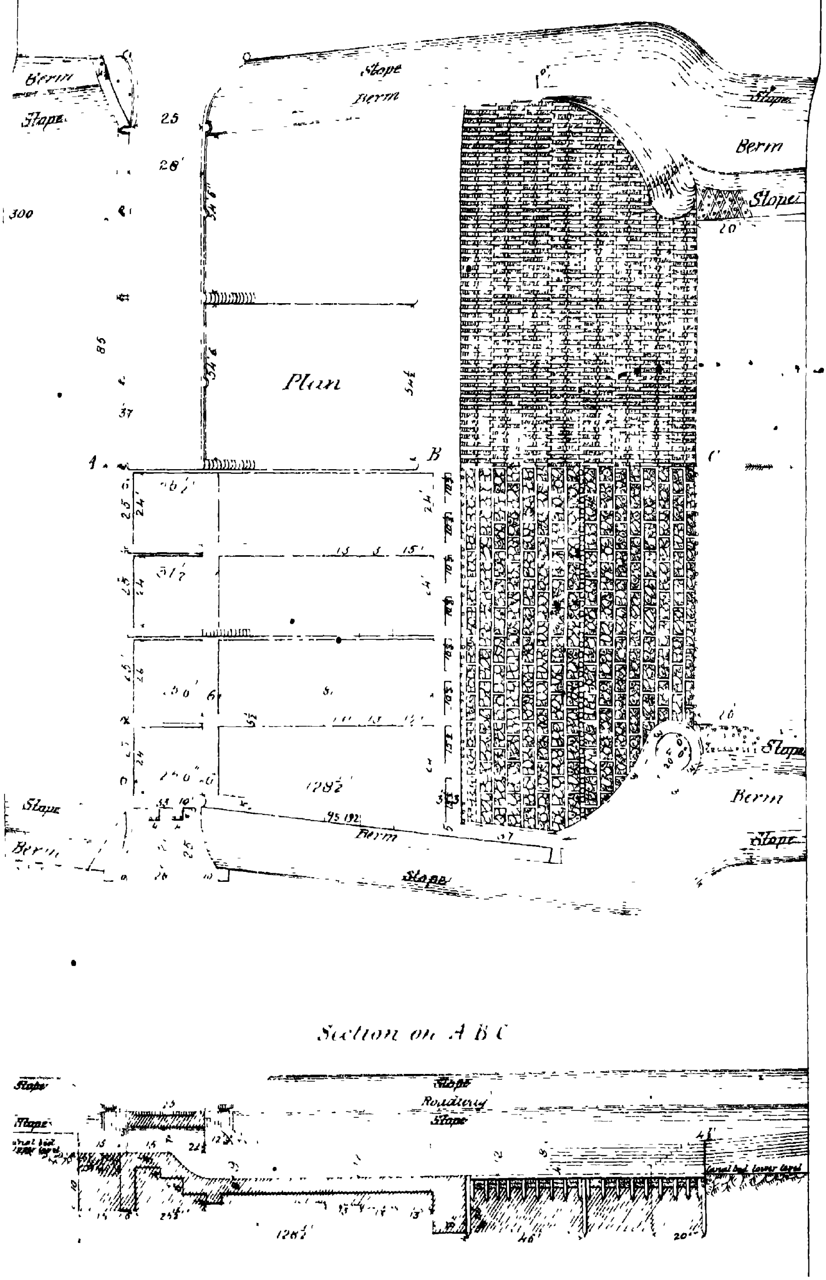
AC, DB } Perpendicular to Flooring.

Bisect A 1, and from the point of bisection at *a* draw a perpendicular cutting the line A C at C.

Join C 1, prolonging the line until it cuts the line D B at D.

From the points C and D as centres draw the curves of the ogee.

OGEE FALL—GANGES CANAL.



by revetments, equal in height to the dividing walls. These flanks, instead of being in prolongation of the alignment of the bridge abutments, expand outwardly, gaining, on their arrival at the tail of the masonry platform, an excess of 20 feet in width. At a distance of 37½ feet from this point, the flanks make a slight curve inwards, terminating (on an imaginary line drawn in prolongation of the pier next to the abutment) in massive projecting jetties. Between, and on the flanks of these two jetties, lines of piles, and other protective arrangements are distributed, so as to secure the safe passage of the water over the floorings, and to admit of the current escaping from the works with as little tendency to danger as possible. The depth to which the curtain or upper foundation wall is carried is equal to 20 feet; that of the tail, with the flank revetments and jetties, is also 20 feet.

70. The result of experience seems to show that the vertical falls with gratings as used on the Baree Doab Canal, or the best that have yet been invented; their construction will be understood by the inspection of the Plate.

The grating consists of a number of wooden bars resting on an iron shoe built into the crest of the fall, and on one or more cross beams, according to the length of the bars. These bars are laid at a slope of 1 in 3, and are of such length that the full supply level of the water in the canal tops their upper ends by half a foot. The scantling of the bars, as well as that of the beams, should of course be proportioned to the weight they have to bear, plus the extra accidental strains to which they are liable, from floating timber for instance, which may possibly pass between the piers and so come in contact with the grating. In consideration of strains and shocks of this nature the supporting beams are set with their line of depth at right angles to the bars instead of vertically.

The dimensions of the bars used on falls of the Baree Doab Canal, where the depth of water is 6·6 feet, are as follows :—

Deodar wood.

Lower end of bars, 0′·50 broad × 0′·75 deep,

Upper end of bars, 0′·25 broad × 0′·75 deep,

and they are supported on two deodar beams, each measuring 1 foot in breadth × 1·5 foot in depth : the first beam being placed at a distance of 7·5 feet (horizontal measurement) from the crest of the fall, and the

second 7·5 feet beyond the first beam. The bars of the grating on these Falls were originally placed touching each other (side by side) at their lower ends, as there was not then a full supply of water in the canal. *There were thus 20 bars in each 10-foot bay. Since then the number of bars has been successively reduced to 19 and to 18, the present number.* The reduction of the number of bars and the equal spacing of the remaining bars is done with ease, as they can be pushed sideways in the iron shoe and along the beams, to which latter they are held with spike-nails. Once the correct spacing is arrived at, cleats and blocks are preferable to spike-nails.

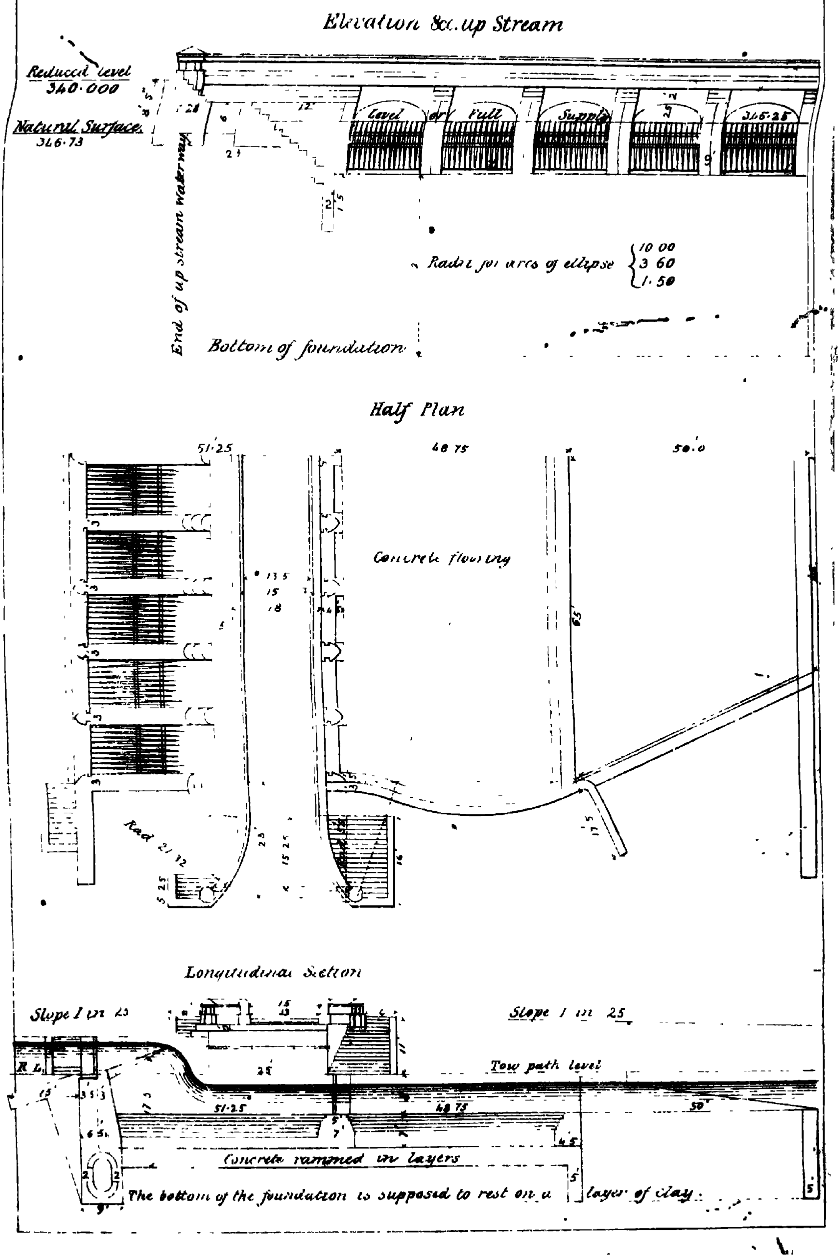
The bars are undercut from the point where they leave the shoe, *i. e.*, from the crest of the fall, so as to make each space as it were "an orifice in a thin plate," and it facilitates the escape of small matters which may be brought down with the current. Large rubbish which accumulates on the grating is daily raked off and piled on one side of the fall. This is done by the establishment kept up for the neighbouring lock. There is considerable advantage in thus clearing the canal of rubbish which would otherwise stick in rajbuha heads, on piers of bridges, &c., or eventually ground on the bed of the canal and become nuclei of large lumps and silt banks.

71. The effect of a fall occurring at the end of a canal reach, is to increase the velocity, and diminish the depth of the water for a considerable distance above the fall. The increase and diminution are gradual from the point where this action commences, down to the fall itself where, of course, they attain a maximum, so that the depth of water passing over the fall is very much less, as the velocity is very much greater, than the normal depth and velocity above. This increase of velocity before the water reaches the fall, produces a dangerous scour on the bed and banks of the canal, and in order to guard against this, it has been found necessary to head up the water at the falls on the Ganges Canal by means of sleepers dropped in the grooves of the piers, which has virtually increased the height of the fall, and has been one cause of the flooring suffering in places from the violent action of the water. It has also been proposed to narrow the falls so as to produce the same effect.

72. The method most commonly adopted, however, is to raise the crest of the falls by a masonry weir; and the height to which it is neces-

VERTICAL FALL WITH GRATING.

BAREE DOAB CANAL.



given by Colonel Dyas:—

Discharge over Fall (complete) $= ml \left(h + \frac{v^2}{2g}\right)^{\frac{3}{2}} = ml \left(h + \frac{n^2d}{2gs}\right)^{\frac{3}{2}}$ and discharge in an open channel $= A\,n \left(\frac{d}{s}\right)^{\frac{1}{2}}$

In which equations—

A = Sectional area of open channel.

d = Hydraulic mean depth of same.

s = Length of slope to fall of one in same.

v = Mean velocity of current in same.

h = Height of surface of water in same, above crest of fall.

l = Length of crest of fall.

m = A co-efficient determined by experiment, varying from 2·5 to 3·5.

n = A co-efficient determined by experiments, varying from 75 to 95.

The discharge in the open channel and that over the Fall are identical, hence we have—

$$m\,l\left(h + \frac{n^2d}{2gs}\right)^{\frac{3}{2}} = A\,n\left(\frac{d}{s}\right)^{\frac{1}{2}}$$

from which we get—

$$l = \frac{1}{m}\,\frac{2\,Agns\sqrt{2dg\,(2ghs + n^2d)}}{(2ghs + n^2d)^2}$$

and if we put $g = 32{\cdot}19083$, $m = 3$, and $n = 90$, we shall have

$$l = \frac{{\cdot}02133\,As\sqrt{d\,({\cdot}008hs + d)}}{({\cdot}008hs + d)^2}$$

$$h = \left(\frac{A^2dn^2}{m^2l^2s}\right)^{\frac{1}{3}} - \frac{nd^2}{2gs} \text{ and}$$

if g, m, and n, are as before

$$h = \left(\frac{900\,A^2d}{l^2s}\right)^{\frac{1}{3}} - 125{\cdot}8122\,\frac{d}{s}.$$

Having thus got the value of h, deduct it from the depth of water in the channel, and we have the height to which the weir should be raised above the true bed of the canal.

73. Where gratings are used, these act instead of a weir in checking the velocity of the water above the falls, and the principle to be adopted in spacing the bars is to arrange them so that the velocity of no one thread of the stream shall be either accelerated or retarded by the

proximity of the fall. This effected, it is evident that the surface of the water must remain at its normal slope, parallel to the bed of the canal, until it arrives at the grating.

To take an example, let us assume that V (mean velocity) = 0·81 v (surface velocity), and U (bottom velocity) = 0 62 v (surface velocity in *every vertical line of the current flowing naturally. Then, if we make V = 2·5 feet per second, we shall have the following velocities at the* given depths below surface in a stream 6 feet deep.

Depths below surface.	Velocities (feet per second).	Remarks.
Surface, ...0	3·0864	Common difference 0·1955, nearly.
1	2 8909	
2	2 6955	
Centre, ...3	2 5000	
4	2 3046	
5	2 1091	
Bottom, ...6	1 9136	

What is required, then, is to shape the sides of a given number of bars placed in a given width of bay, so that the above velocities may be maintained till the water touches the grating, when, in consequence of the clear fall, the velocity becomes considerably accelerated. This accelerated velocity multiplied by the reduced area (of space between the bars) should give the same discharge, with the canal running full, as the product of the original normal velocity and the original undiminished space, the width of which is, of course, the distance, between the centres of two contiguous bars.

Thus, taking the lowest film (along the bed of the canal) whose normal velocity is 1·9136 foot per second, and supposing 20 to be the number of bars in each 10-foot bay, then the undiminished space for each portion of the stream will be half a foot, which multiplied by the above velocity gives a product of 0·9568. Again, taking the same lowest film as it passes through the grating, with a clear fall, and under a head of pressure of 6 feet, we find its velocity to be 19 654 feet per second. Now, if we call the required width of space between the bars at this point x_6, and assume the co-efficient of contraction to be 0·6, we shall have $x_6 =$

$$\frac{0\cdot9568}{19\cdot654 \times 0\cdot6} = 0\cdot08 \text{ foot.}$$

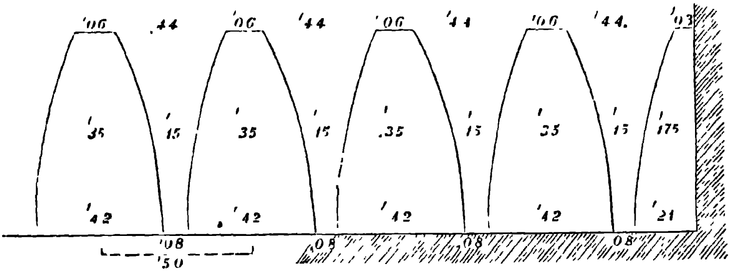
Similary, taking the film on the level of the tops of the bars, or 0·5 foot below the surface of the water, the normal velocity of which is 2·9887, the undiminished space being, as before, 0·5 foot, we get a product of 1·4944; and as the velocity of the film falling through the bars is 5·673 *feet per second, we get*

$$x_b = \frac{1{\cdot}4944}{5{\cdot}673 \times 0\,6} = 0{\cdot}44 \text{ foot.}$$

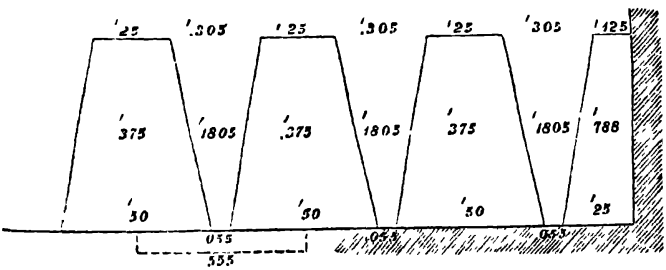
And, lastly, taking the central film, the normal velocity of which is 2·5 feet per second, we have a product of 1·25, and as the velocity of the same film passing through the grating is 13 89 feet per second, we get

$$x_c = \frac{1{\cdot}25}{13\,89 \times 0\,6} = 0{\cdot}15 \text{ foot.}$$

Hence it is seen that the sides of the bars should be cut to a curve



convex towards the open space; but in practice this nicety is scarcely requisite, and they may be made thus—



74. The above remarks have been limited to a consideration of the effect caused by the grating on the channel *above* the fall. Its effect on the channel *below* the fall is equally important; for the present it may suffice to remark that the formula in use on the Baree Doab Canal for the depth below the lower bed of the channel is

$$x = \sqrt{h}\,\sqrt[3]{d}$$

in which empirical equation,

x, is the required depth of cistern,

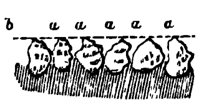
h, the height of fall, or the difference of level between the surface of water above the fall and the surface of the water below it, and d, the full supply depth of water in the channel.

All the cisterns with depths thus obtained have answered admirably, having never required the slightest repair since they were built.

75. *Instead of falls, and to accomplish the necessary change of level, Rapids have been employed with success on the Baree Doab Canal, i. e.,* the fall is laid out on a long slope (15 to 1) instead of by a single drop; the slope being paved with boulders, laid with or without cement, and confined by walls of masonry in cement, at intervals of 40 feet both longitudinally and across stream. The longer the slope, the more gentle is, of course, the action of the water; but the greater, also, is the quantity of masonry employed. In general, the choice between the two is a mere question of expense and material available. On the above canal, rapids were adopted wherever boulders were procurable at moderate cost.

Boulders are the proper material for the flooring of a rapid, and brickwork should not be used in contact with currents with such high velocities. Even the very best cannot stand the wear and tear for any length of time, and stone should be used for all surfaces in contact with velocities exceeding (say) 10 feet per second.

The boulders used should generally be grouted in with good hydraulic mortar and small pebbles or shingle. Dry boulder work is not to be depended on for velocities higher than 15 feet per second, even when they weigh as much as one maund each, and are laid at a slope of 1 in 15. There should be no attempt made to bring the surface of the boulder work up smooth, by filling in the spaces *a a a*. All that is necessary is to lay the boulders and to pack them so that their tops are pretty well in



line as *b c;* any further filling in would stand a good chance of being washed out very soon, and if it remained, its effect would be to increase the velocity of the current on the rapid by diminishing the resistance presented to the water by the rough boulder work.

76. The Baree Doab Canal Rapids have tail walls of peculiar construc-

tion for the purpose of destroying back eddies, and of protecting the Canal banks below the rapid from the direct action of the current. These tail walls are intended to be so arranged that the heaviest action *of water at the foot of the rapid shall take place in the widest part, and they incline towards each other from this point so as to direct the set of the stream well to the centre of the canal, thus protecting the banks* from the direct action of the current for a considerable distance. At the same time, as may be seen from the longitudinal section, the tail walls are not kept at their full height throughout, but beginning (a little below the point where the curve ends) at the level of full supply only, they gradually become lower and lower (slope 1 in 20) till they vanish altogether, where they are on the same level as the bed of the canal. The triangular spaces behind the tail walls in plan are filled in with boulders (dry) to the level of the top of the sloping tail wall; when the full supply is running, these tail walls are submerged and invisible, the rapid appearing to end just below the end of the curve.

In case no such tail walls are given, the banks should be faced with boulder work, *jamah* or piling, for a length on each side, of (say) 300 feet below the rapid. Some such protection will always be necessary for the banks.

77. The maximum velocity of current which a boulder rapid will stand without injury cannot be exactly determined. But experience has proved that a boulder rapid with a flooring composed of boulders not less than one maund in weight each, well packed *on end*, and at a slope of 1 in 15, will *not* stand a mean velocity of 17·4 feet per second.

78. It is clear that navigation must be interrupted by Falls, and *Locks* are therefore necessary for the passage of boats, up or down, the action of which may be understood by an inspection of the Plate. Suppose that a boat has to pass from the upper to the lower level, the upper gate being closed, and the lock chamber being empty. The lower gate is first closed, the sluices of the upper gate are raised by which the lock chamber is filled with water; the upper gate itself is then opened and the boat passes into the lock chamber when the upper gate is again shut. The lower gate sluices are then opened, by which the water in the chamber flows into the lower level, the boat sinking with it; the lower gate itself is then opened and the boat passes out. The process has, of course, to be reversed if the boat has to ascend from the lower to the higher level.

The locks may either be arranged on one side of the main channel in a bay adjoining the falls, or a separate navigable channel may be provided round the falls with the lock arranged at any convenient point on its course. This has been done on the Ganges Canal, but it is an expensive arrangement, and the small channels have been troublesome from their silting up and from the growth of weeds in their beds. The only advantage of the arrangement is that it obviates the risk of boats being carried over the falls; but with proper precautions, such as a floating boom across the main channel above the bays of the falls, this danger can easily be prevented.

The size of the lock chambers depends on the sort of boats used and the amount of traffic. On the Ganges Canal they are 100 × 16 feet.

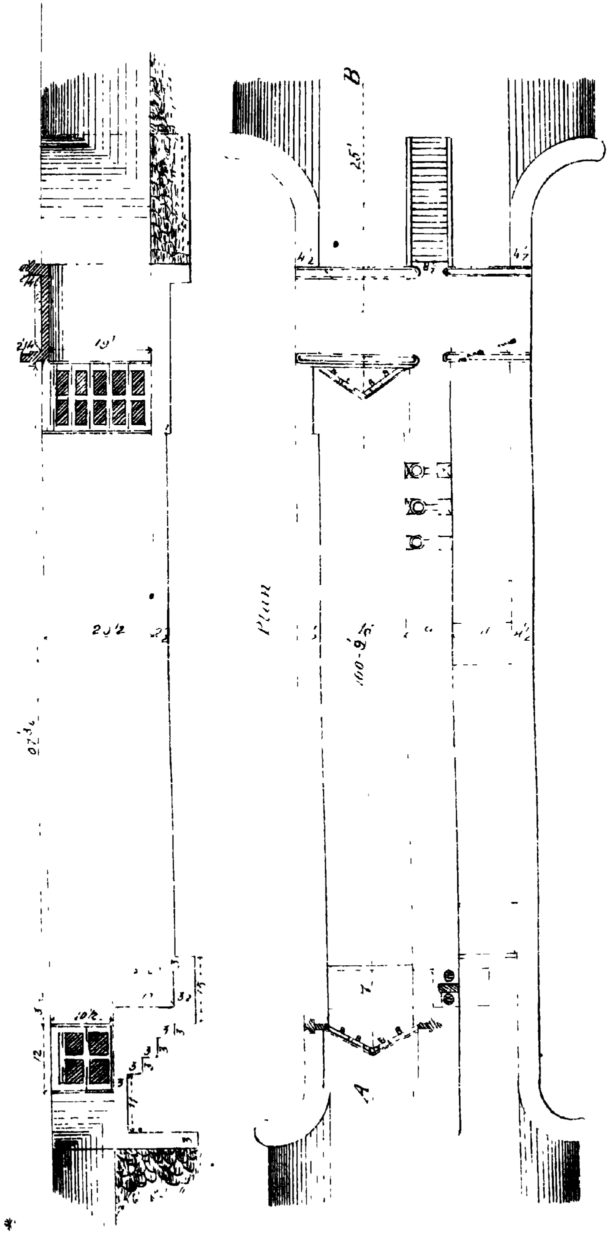
If the traffic is heavy, a double set of locks may be required; for the up and down traffic to be worked together.

79. *Mills* for grinding corn, &c., may be advantageously established wherever there are falls on the canal, particularly if in the neighbourhood of a town or large village. A separate channel may be cut for the mill-race, joining the main canal again below the fall. The following is a description of the *Pun-chukkee*, or native corn mill, in general use on the canals in Upper India:—

A horizontal water-wheel with floats placed obliquely, so as to receive a stream of water from a shoot or funnel, the said float-boards being fixed in a vertical axle passing through the lower mill-stone, and held to the upper one by a short iron bar at right angles, causing it to revolve with the water-wheel,—the axle itself having a pivot working on a piece of the hardest stone that can be procured from the shingle near at hand:—this with a thatched roof over it, and the expense and trouble of digging a cut so as to take advantage of a fall of water,—are the only articles required in this very simple mill. The plan is so obviously good, not only for the means gained, but also from the simplicity, rendering the whole almost independent of repair, and so intelligible in its parts as to come within the comprehension of the simplest understanding, that it has been adopted generally in all the canals in the Delhi district, as well as in those of the *Doab.*

On reference to the accompanying Plate, it will be seen that there is only one motion, and that supposing the materials are good, the permanency of the machinery depends entirely on the lower pivot. It will also be evident that there is not a part of the whole machinery that could not be repaired and put in perfect order by the commonest village workman, a matter of importance in the absence of mechanical skill and practised workmen. Whereas in the plainest undershot wheel applied to a mill for grinding corn, there are no less than three wheels of different descriptions; the change of vertical to horizontal motion;—and three pivots to keep in order, with a friction, even under the most skilful management, tending constantly to disarrange

LOCKS—GANGES CANAL.



(as used in Upper India.)

Fig 1

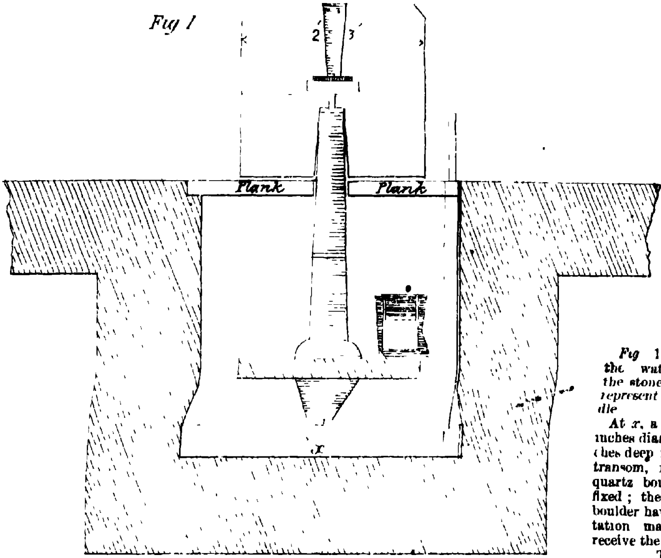


Fig 2

Fig 4
Scale, ½ inch - 1 f.t

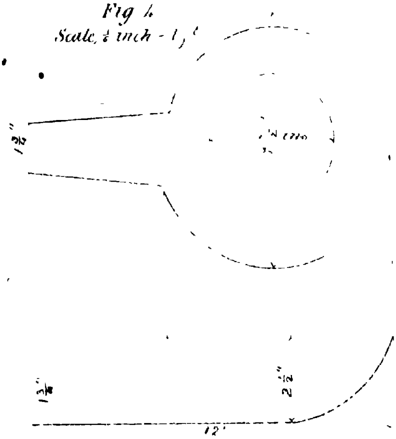


Fig 3
Scale ½ inch to 1 f.t

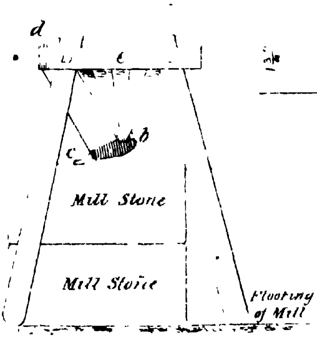


Fig 1 Elevation of the water-wheel, with *the stones in section to represent the iron spindle*

At *x*, a hole of about 4 inches diameter and 4 inches deep is made in the transom, into which a quartz boulder is firmly fixed; the said stone or boulder having an indentation made in it to receive the pivot

This pivot consists of another stone of the same quality of about 4 or 5 inches long and 1 inch square, which is firmly fixed into the tail of the arbour (see *y*) The above stones are picked up in the beds of the mountain rivers, and are used as they are found without anystone cutting.

Fig 2 Plan of water-wheel, 30 float boards of sissoo wood, the float boards 12 inches long with a spoon sunk 4 inches.

Fig. 3. Sketch of mill stones, with basket stand, &c.

a Hopper or basket

b Shoe

c. Feeder, or small piece of wood hanging to one lip of the shoe and resting on the mill-stone each revolution of which gives the shoe a jog, causing the corn to run constantly from the hopper through the shoe

d String attached to the opposite lip of the shoe, to which the feeder is, and by tightening or loosening which, the discharge of corn is regulated.

e Stand

Fig 4 Shoe on a large scale; this is generally cut out of a block of dak (*Buteo frondosa*), or any wood easily worked.

Scale ½ inch = 1 foot.
12' 6 0'' 1' 2' 3' feet.

the parts, and render the accompaniments of a forge and blacksmith's shop absolutely necessary to keep the mill in order.

On the canals it has been found worth while to construct permanent buildings for these corn-mills, and although keeping most strictly to the original simplicity of the machinery, they are set up with greater care, and means are given for regulating the motion, &c., which renders the whole as perfect as it can well be.

It would appear that a fall of water (that is to say, the difference of level between the surface of the head supply and the float-boards of the water-wheel), equal to three feet, is the minimum in which this species of machinery can be used with any good effect ; and it has been found that with a fall of three feet, the dimensions of the shoot or funnel require an addition in width, to obtain that by weight of water, which the smallness of the fall will not give by velocity alone, and in the dimensions of shoot given to those of a higher class.

80. The following are the particulars of mills on the Eastern Jumna Canal, divided into three classes from the depth of the fall ; the width of shoot on the sill or waste-board being 12 inches, and the discharge per second averaging 6·5 cubic feet ; the diameter of mill-stones 27 inches, and thickness 12 inches ;—the corn being ground into *atta* or coarse flour.

Class.	*Fall of water.*		*Atta ground per hour.*	
	ft.	in.	md.	seers.
No. 1	7	6	1	26
2	5	6	1	5
3	3	6	0	17

The common mills used in the Jumna and mountain-streams, are said to grind from 5 to 7 maunds of atta per day, or in 24 hours ; the machinery being of the rudest description, the supply of water very small, and a great part of that escaping through the shoot before it touches the water-wheel.

The return to Government on the mills is obtained generally by farming them out to contractors for fixed periods, who pay so much per day as long as a supply of water equal to that entered in the contract is provided, regulated by the depth of water on the sill or waste-board ; this return of course varies not only from the powers of the mill, but also from their position relatively to populous towns and cantonments.

The stones used on the canals are chiefly those from the quarries near Agra, Rupbas and Fatihpur Sikri, a course-grained sandstone, which requires the chisel every second day—there are three sizes used—

First size, diameter 36 inches, depth 12.
Second „ „ 30 „ „
Third „ „ 27 „ „

The two latter are in most general use Stones of the usual quality last for about two or three years, that is to say, at the end of that period, a new upper stone is provided, and the old one placed below.

CHAPTER V.

DRAINAGE WORKS—AQUEDUCTS—INLETS—DAMS—*SUPERPASSAGES.*

81. We now come to the very important class of works by which the canal is carried over the various obstacles to be met with in its course.

The great expense and intricacy of the works in the upper portion of most canals in Northern India, is owing to the number of drainage lines running from the hills, across which the canal has to be carried before it can be brought fairly out on to the general water-shed of the country. Of course, so far as it can be laid out, it is made parallel to these lines, and not perpendicular to them, but owing to their numerous ramifications, and to the oblique line at which the canal has to start, in order to get clear of the river before it can be carried on in a parallel direction, it always happens that many of these drainage channels have to be crossed; and as many of them are swollen to formidable torrents in the rains, and all of them are troublesome, the fall of their beds being great, and their course often very shifting, it becomes a matter of considerable consequence how to provide for them.

82. Much may be done by *diversion*, *i. e.*, by altering their course so as to make them run clear of the canal. A very instructive example in this way was the Chukkee torrent on the Baree Doab Canal, for the passage of which costly works were originally designed. The Chukkee, at the time of the commencement of the canal works, had two outlets; just above the crossing point of the canal, the main channel divided; one, the larger branch running into the Beas, the other into the Ravee. This latter was embanked across at the bifurcation, by boulder dams and spurs of the same material, protected at the extremity by masonry revetments. By these means, the whole of the water was forced to flow into the Beas, and the expense of the works for the canal crossing saved.

If, however, the torrent cannot be diverted, it will appear that there are three cases under which it may have to be crossed. 1st, When it is on a lower level than the canal; 2nd, When on the same level; 3rd, When it is on a higher level.

83. In the *first* case when the torrent or drainage line is on a lower level, the canal is carried over it on an *Aqueduct.* The valley drained by the torrent will be embanked across in the usual way, care being *taken that sufficient water-way is provided under the aqueduct for the torrent to pass when in flood. Now, an aqueduct only differs from a bridge in having to carry a water channel over it instead of a road or railway.* The bridge part may be made of wood, iron or masonry. The channel must be water-tight and strong enough to carry the water, of course. Sometimes an iron trough is used, but for large aqueducts, a masonry channel is usually employed, supported on arches, resting on piers and abutments like an ordinary bridge.

84. The most celebrated instance of this class of works is the Solani Aqueduct on the Ganges Canal.

This work, by which the canal is carried across the valley of the Solani river, consists of an earthen embankment or platform, raised to an average height of sixteen and a half feet above the country, having a base of 350 feet in width, and a breadth at top of 290 feet. On this platform, the banks of the canal are formed, 30 feet in width at top, and 12 feet in depth. These banks are protected from the action of the water by lines of masonry retaining walls formed in steps extending along their entire length, or for nearly two and a quarter miles north of the Solani.

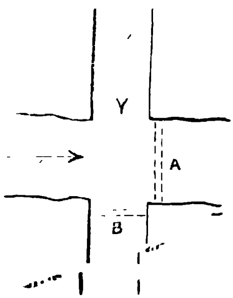
The river itself is crossed by a masonry aqueduct, which is not merely the largest work of the kind in India, but one of the most remarkable for its dimensions in the world. The total length of the Solani aqueduct is 920 feet. Its clear water-way is 750 feet, in fifteen arches of 50 feet span, each. The breadth of each arch is 192 feet. Its thickness is 5 feet; its form is that of a segment of a circle, with a rise of 8 feet. The piers rest upon blocks of masonry, sunk 20 feet deep in the bed of the river, being cubes of 20 feet side, pierced with four wells each, and undersunk in the usual manner. These foundations, throughout the whole structure, are secured by every device that knowledge or experience could suggest; and the quantity of masonry sunk beneath the surface is scarcely less than that visible above it. The piers are 10 feet thick at the springing of the arches, and 12½ feet in height. The total height of the structure above the valley of the river is 38 feet. It is not, therefore, an imposing work when viewed from below, in consequence of this deficiency of elevation: but when viewed from above, and when its immense breadth is observed, with its line of masonry channel, nearly three miles in length, the effect is most striking.

The water-way of the canal is formed in two separate channels, each 85 feet in width; the side-walls are 8 feet thick and 12 feet deep, the depth of water at full

supply level being 10 feet. A continuation of the earthen aqueduct, about three quarters of a mile in length, connects the masonry work with the high bank at Roorkee, and brings the canal to the termination of the difficult portion of its course.

85. The *second* case is where the torrent is crossed on the same level. It may be a small drainage channel only occasionally filled, or at least never bringing down but a small body of water. In that case it simply becomes an *Inlet*, and is provided for by an arched opening through the embankment, by which the water can be passed into the canal. In this way all mere surface drainage is provided for at various convenient points, though, as the course of the canal, when once clear of the difficult ground above, lies close to the watershed of the country, the amount of intercepted drainage is small.

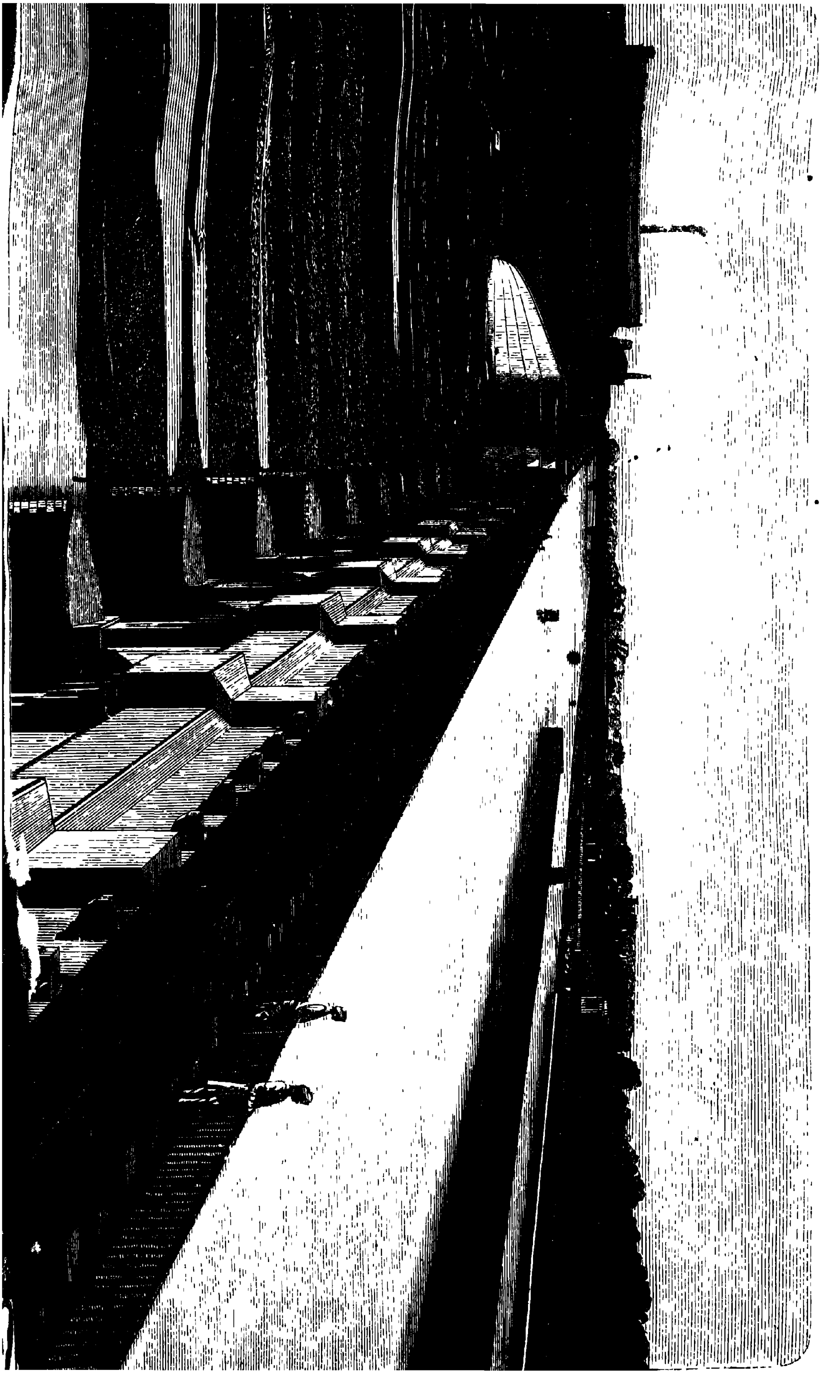
But if the torrent is of large dimensions and bringing down a great volume of water at a high velocity, the above method will not answer; the water, loaded with silt, would choke up the canal bed, and its force would destroy the embankments and do irretrievable damage. More elaborate arrangements have therefore to be made, the nature of which will, however, easily be understood from the following diagram.



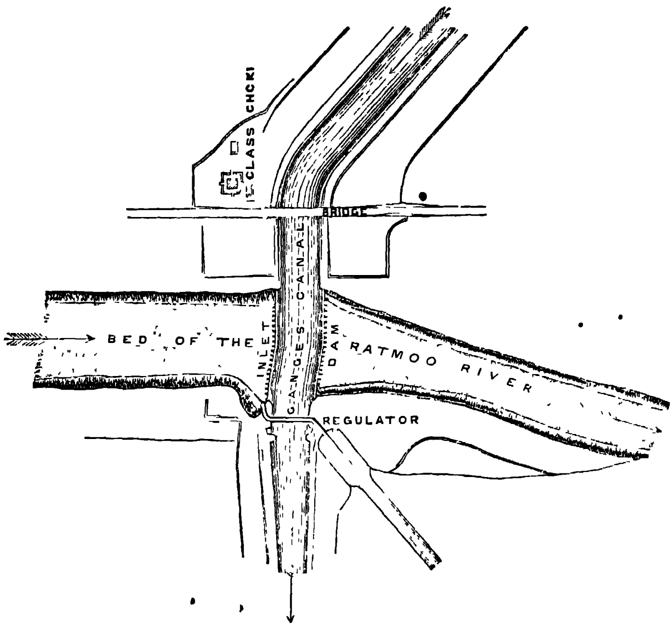
B is a regulating bridge across the canal channel provided with the usual sluice gates. A is a dam across the channel of the torrent provided with flood gates. Under ordinary circumstances, A is closed and B is open, so that the canal water flows along as usual. But, when the torrent is in flood, then A must be open and B closed, so that the flood-water may cross the canal, and run down its own channel. The bed of the torrent below the dam must be paved for a certain length to prevent erosion, and the sides of canal and torrent have to be revetted for a considerable length to prevent their being cut away by the water.

86. The finest example of these works is at Dhunowrie, on the Ganges Canal, where the Rutmoo torrent is passed.

The dam itself consists of 47 sluices of 10 feet in width, with their sills flush with the canal bed, separated by piers of $3\frac{1}{2}$ feet. The above are flanked on each side by five overfalls of the same width, having their sills raised to a height of 6 feet, with intermediate piers of the same dimensions as those in the centre sluices. On the extreme flanks are platforms raised to a height of 10 feet above the canal bed, and corresponding in height with the rest of the piers. These elevated platforms, which



are 17 feet in length, are connected with the revetment esplanade by inclined planes of masonry carried through the flanks of the dam.



The amount of waterway, therefore, through the sluices, up to a height of 6 feet is equal to 470 feet in width ; to a height of from 6 to 10 feet, it is increased to 570 feet, and when flood water rises above that height, the water passes over the full expanse of the masonry, which is equal in width to 800 feet.

For the ten sluices on the flanks, the closing and opening is effected by sleeper planks for which grooves are fitted to the piers For the centre openings, drop gates are provided, which are retained in their upright position by chains against the pressure of the canal water from the inside, and which, on the occurrence of a flood, can be dropped down on the flooring by releasing a catch, and allow the flood water to pass through the openings. When the flood is over, the gates are raised upright by a movable windlass, the pressure of the water being temporarily taken off by dropping planks into the grooves.

On the down-stream side of the dam, a platform of box-work, filled with river-stone extends to a width of $43\frac{1}{2}$ feet from the masonry flooring , this is held in position by double lines of 20-feet piling, strongly clamped together by sleepers fastened on to the upper surface, the slope of which is $2\frac{1}{4}$ feet on an incline down-stream.

The regulating bridge has ten water-ways each 20 feet broad, and provided with gates to prevent any flood-water passing down the canal. In addition to this, there is a roadway bridge, and about a mile of revetment walls, all resting on blocks of brick masonry, sunk to a depth of 20 feet below the canal bed. The whole of this work is

protected by a forest of piles, and an enormous number of bottomless boxes filled with boulders.

By a double tunnel, upwards of 500 feet long, the river, when not in flood, flows *under* the canal.

87. The patent objection to this kind of work is that it requires a permanent establishment of men on the spot to work it, and that, if they are careless or neglectful, a sudden flood may do serious damage. On this account level crossings are to be avoided whenever it is possible.

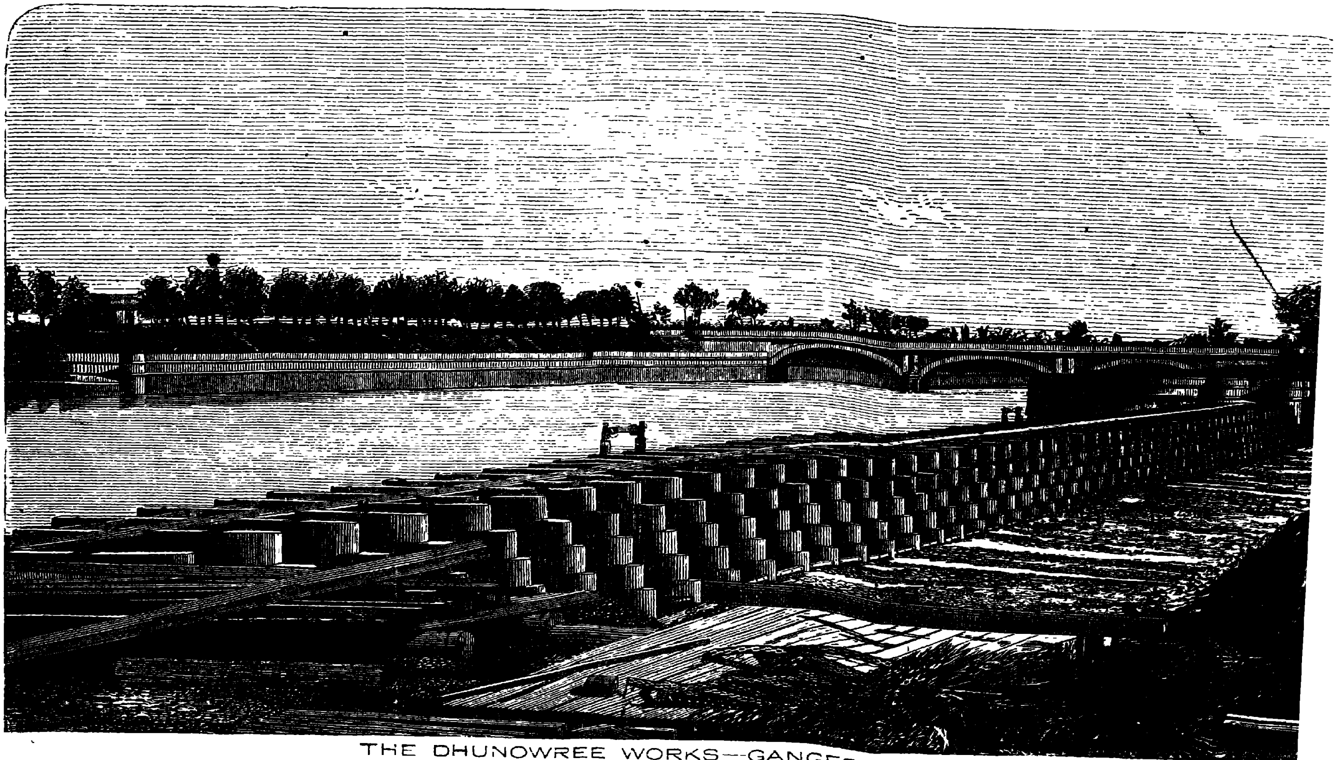
88. The *third* case is where the torrent crosses on a higher level; when it has to be carried over on an aqueduct, generally called, in that case, a *Superpassage*, to distinguish it from the first case where the canal *flows over the torrent. This, of course, becomes a very expensive and troublesome work, as a large water channel has to be provided to carry* any extraordinary flood over the canal in safety, and sufficient head-way must be allowed under the superpassage so as not to interrupt the navigation; for this purpose the canal water can be dropped to the required level by a masonry fall, a lock being provided for navigation purposes. The torrent will probably require constant watching to prevent its shifting its course and attacking the canal bank.

It possesses, however, the great advantage of keeping the canal completely free from any influx of flood-water from the torrent, which is always more or less heavily charged with silt. It has the additional recommendation of not requiring the maintenance of a large establishment every rainy season, as in the case of a level crossing, where the regulating apparatus must be worked by manual labor; and lastly, the canal supply can thus be kept up uninterruptedly, there being no necessity to shut it off at the crossing to keep the silt laden flood water out of the channel below. These recommendations apply equally to passage by "aqueduct," and render them both generally preferable to a dam when the levels will admit of the substitution.

89. There are two fine examples of superpassages in the Northern Division of the Ganges Canal, by which the Puttree and Ranipore torrents are crossed. These have a clear water-way between the parapets of 2 and 300 feet, respectively, and when the torrents are not in flood, they are used as bridges of communication.

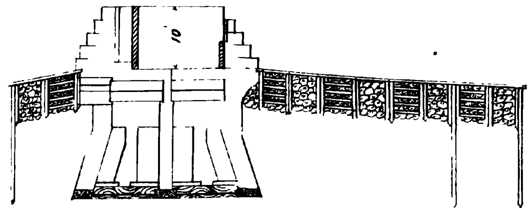
I have preferred, however, to give a detailed description of the Seesooan Superpassage, as designed by Major Crofton for the Sutlej Canal.

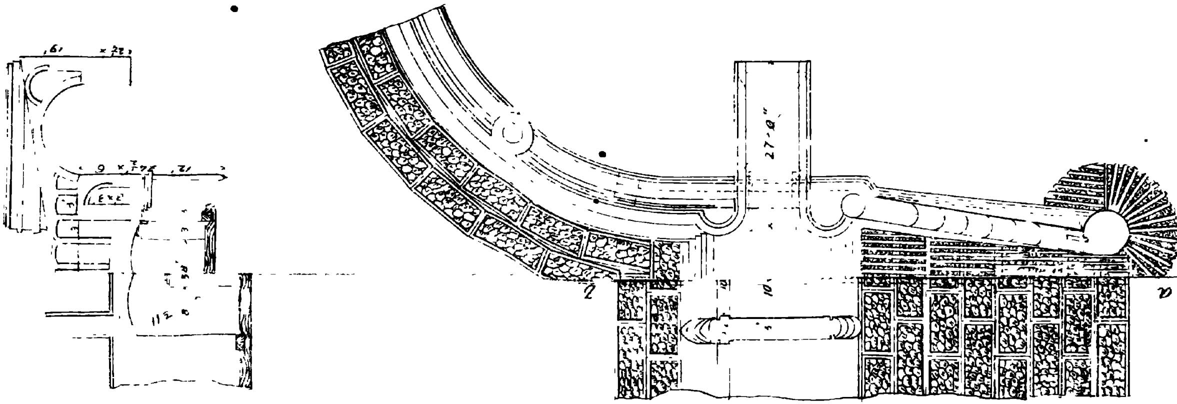
Taking the catchment basin of the Seesooan to be 8 miles in length by 3 miles in

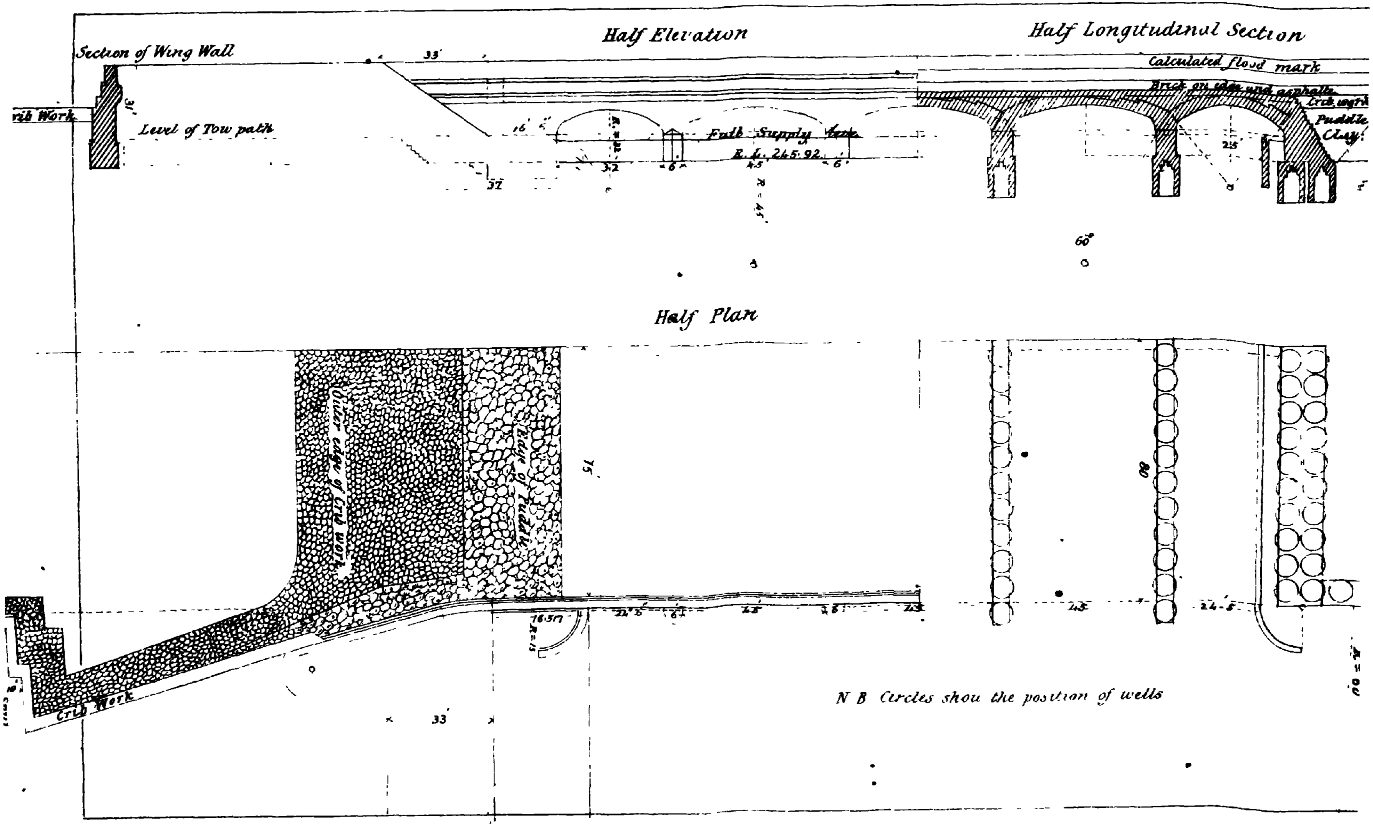


THE DHUNOWREE WORKS—GANGES CANAL.

Section on a b







Half Elevation
Half Longitudinal Section
Section of Wing Wall
Calculated flood mark
Brick on edge and asphalte
Crib work
Puddle Clay
Level of Tow path
Full Supply Line
R.L. 245.92
R = 45'
Half Plan
Outer edge of Crib work
Edge of Puddle
Crib Work
N B Circles show the position of wells

width, we obtain an area of 24 square miles, which would give a maximum rain-fall to be carried off of 7,752 cubic feet per second, agreeing very closely with the discharge calculated from the area of the section at the canal crossing, *with the velocity due to a declivity of 1 in 794 ; to pass of this discharge, a water-way of 150 feet wide* by $6\frac{1}{2}$ feet in depth, on the above declivity will be required.

The difference of level between the beds of the canal and the torrent is 21·93 feet, which is thus disposed of :—

Depth of water in canal,	.. ..	7·00
Headway up to soffit of arch,	.. ..	10·00
Thickness of arch,	.. ..	3·00
Brick-on-edge flooring,	.. ..	1·93
	Total, ..	21·93

The canal channel will be spanned by three central arches of 45 feet span each, and two at the sides of 32 feet each; tow-paths, $7\frac{1}{2}$ feet wide in the clear, will be carried under each side arch, leaving an aggregate water-way of 184 feet. The mean water-way of the canal channel is only 177 feet; the addition is made in this work, in consideration of the impossibility of increasing its dimensions should the canal be required to carry a larger supply hereafter. The water-way for the torrent above, is projected in one channel 150 feet wide at bottom, with side walls (head walls of the work) 10 feet in height, 5 feet thick at the base, 4 feet at top ; the flooring over the arches will be formed of asphalte or some substance impervious to water, the upper surface being covered with some hard material, probably a layer of kunkur slabs ; the backing of the abutments will be of puddled clay covered with a flooring of kunkur, slag or boulders, packed in cribs.

CHAPTER VI.

HEADWORKS—DAMS—REGULATORS.

90. It remains to describe the works which are required for *admitting and controlling* the supply of water in the canal, and for *distributing it for the purposes of irrigation.*

The works at the head consist essentially of a *Dam* across the river, by which the water is held up and checked in its onward flow, and a *Regulator* across the head of the canal channel, by which the proper quantity of water is admitted.

In many cases, the canal is taken out of a branch of the main river, and the permanent dam is thrown across the branch only, the water being diverted from the main stream into the branch by temporary dams constructed of boulders, which are swept away on the rise of the river, and are annually replaced. This arrangement has chiefly been due to the very heavy expense which would be incurred in throwing a permanent dam across the main river itself, and perhaps, to a fear of meddling more than is absolutely necessary with the normal flow of such rivers as the Ganges, Jumna, &c.

91. But the disadvantages of the arrangement are very serious, as will be readily understood with a little explanation. The great rivers rising in the Himalayas are at their lowest during the months of December, January and February. In March and April the increasing heat begins to melt the snow on the high ranges, and causes the river gradually to swell and rise until the month of June, when the periodical rains commence, and the river rises still more in June, July and August, in which last month it attains its maximum, falling rapidly in September, October and November.

Now, the months in which the water is more especially valuable to the cultivator are February and March, when the spring crop is coming to maturity, and September and October, just before the same crop is sown,

i. e., at the two periods when the river is beginning to rise, and commencing to fall. It is, therefore, essential that the temporary dams annually erected should be in position in September (if possible), and should be maintained until April; and, in general, they are so; but it not uncommonly happens that a sudden freshet may breach or sweep away these dams before the river has permanently risen for the season, and when it is too late to replace them. And, it is always difficult to get the dams built early in the autumn, partly from the uncertain state of the river which is very liable to freshets, and partly from its being the most sickly season of the year for workmen.

In each case, the valuable rubbee crops suffers, while of course, the annual expense of replacing and repairing these dams is also very great. It is more than probable, therefore, that before long, permanent works will be constructed at the heads of all great canals, so as to have the main stream of the river completely under control, and, not merely the branch from which the canal supply is drawn.

92. Dams are either made solid, when they are called *Weirs* (in Madras, *Anicuts* is the local term), or they may be provided with openings as is generally the case in the Upper Provinces; indeed the term dam is always understood to mean an *open* dam in Northern India, or one partly open and partly closed.

The advantage of the *Weir* is that it is *self-acting*, requiring no establishment to work it, and if properly made, ought to cost little for repair. It is also a stronger construction, better able to withstand shocks from floating timbers, &c. Its disadvantages are that its first cost is generally greater* and that it causes a great accumulation of silt, boulders, &c., above it, and interferes, far more than an open dam, with the normal regimen of the river. It is possible that, in certain cases, this might result in forcing the whole or part of the river water to seek another channel, and the possibility of this should always be taken into account; but if the river has no other channel down which it could force its way, the accumulation of material above the weir would be an advantage rather than otherwise, as adding to its strength. The finest example of weirs are those erected on the Madras rivers, which will be described further on.

The advantage claimed for the open dam is that the interference with

* Not always. The quantity of masonry in a weir is much greater than in an open dam, but the quantity of fine, and therefore expensive work, is less.

the normal action of the river is reduced to a minimum, the strong scour obtained by opening its gates effectually preventing any accumulation of silt above; its first cost too is generally smaller than that of a weir.

93. A *Dam* consists of a series of piers at regular intervals apart, on a masonry flooring carried right across and flush with the river bed, protected from erosive action by curtain walls of Masonry up and down-stream.

The piers are grooved for the reception of sleepers or stout planks, by lowering or raising which the water passing down the river is kept under control. The intervals between the piers may be 6 to 10 feet, which is a manageable length for the sleepers. If the river is navigable at the head, one or two 20 feet openings fitted with gates must be provided to enable boats to pass.

The flooring must be carried well into the banks of the river on both sides to prevent the ends of the dam being turned, and the banks and bed of the river will generally require to be artificially protected for some distance, above and below the dam, to stand the violent action of the water when the gates are partially closed.

The two flanks of the dam for some length are generally built as weirs; that is, instead of having piers and gates, the masonry is carried up solid to a certain height, so that when the water rises above that height, it may flow over the top of it. The advantage of this arrangement is that it affords an escape for water in case of a sudden flood when the dam may be closed, while, when the water is low, they keep it in the centre of the river and away from the flanks, and thereby create a more prefect scour.

94. When the river is subject to sudden and violent floods, damage might be done before the sleepers could be all raised, one by one; it is better therefore to employ flood or *drop-gates* in such a case; that is, gates which turn upon hinges in the piers at the level of the flooring and which when shut are held up by chains against the force of the water. In case of flood, the chains are loosened, the gates drop down, and the water flows over them. Should the intervals between the piers be over 10 feet, there would be a difficulty in hauling the gates up again.

A bridge of communication may be made between the piers of the dam if required. But as it is not desirable to have it obstructed with traffic, it may be merely a light foot bridge, or the intervals may be spanned temporarily with spare sleepers.

The dam and regulator are generally close together and connected by a line of revetment wall.

95. The *Regulator* like the dam consists of grooved piers resting on a firm foundation carried across the *canal* bed. As floods are made to escape down the river, and are shut out from the canal, flood-gates will not be necessary for the regulator, and the water may be admitted and controlled either by planks alone, or as is usual, by a gate moving up and down in the grooves—on to which planks can be dropped when necessary, one by one. The gates are raised or lowered by a windlass and chains; the windlass may be movable, or one may be fixed between every two piers and worked by hand-spikes.

The piers of the regulator are generally connected by arches so as to form a regular bridge of communication across the canal.

The bed and banks must be defended by masonry as in the case of the dam, so as to be safe from the water's action when the gates are open or only partially closed.

The flooring of the regulator at the head of a canal is a convenient datum for all the canal levels. A water-gauge should be fixed on it at one of the piers, so that the amount of water passing into the canal may be accurately known.

96. The following is a description of the dam and regulating bridge at Myapore, the head of the Ganges Canal, shown in the annexed Plate:—

The Dam, which is 517 feet between the flanks, is pierced in its centre by fifteen openings of 10 feet wide each; the sills or floorings of each opening being raised 2½ feet from the zero line. These floorings are so constructed, that if necessary, they may be removed, and a flush water-way be obtained as low as zero. The piers between the above openings are 8 feet in height, so that the elevated flooring leaves the depth of sluice-gate equal to 5½ feet. The piers are fitted with grooves for the admission of sleeper or vane planks.

The centrical sluices are connected to the flanks by overfalls, rising in gradations of one foot on three series; the overfall nearest to the flank being raised 10 feet above the zero point.. The flank walls themselves are 18¾ feet in height, exclusive of cornice and parapet, which rise 5 feet above them. The top of the overfalls on the right and left, as well as that of the piers, is flat; the former being an esplanade varying from 7 to 10 feet in width, which, during dry weather, is connected by a temporary communication formed by planks thrown across the sluice openings. This esplanade is at each extremity terminated by a flight of steps, which gives access to store-rooms; in which, when the dam is laid open, and the wood-work removed, the latter is lodged for security. The two buildings for this purpose are situated on the flanks; their floors are raised 20½ feet from the zero point, and their interior dimensions are 30 feet in length by 16 feet in breadth.

The flank revetments, which are built on the right and left of the down-stream side of the dam, and between which the escape water has to pass, have been designed with an inclination inwards equal to 13 feet on a length of 80 feet.

The transverse width of the dam platform is 44 feet, measuring from the up to the down-stream face of the work. Of this measurement 20 feet 11 inches are given to the tail, which delivers the water upon the natural bed of the river, consisting of large boulders and shingle.

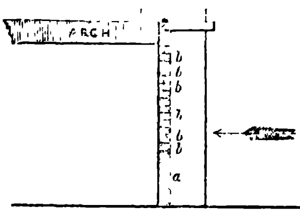
The revetment which connects the right flank of the dam with the regulating bridge, is a plain wall equal in height to the dam flanks, and with a slope or batter of $2\frac{1}{2}$ in 20 feet in height. This revetment, on its approach to within 50 feet of the bridge, terminates in a line of ghâts, or flight of steps, which passes from the higher levels to the bed of the canal. The up-stream wing or flank of this flight of steps corresponds in form with that of the wing of the bridge, with which it has a uniform curve.

The Regulating Bridge has ten bays or openings of 20 feet wide and 16 feet high; each bay being fitted with shutters and apparatus for either opening or closing it. The breadth of the platform on which the piers rest is 48 feet, exclusive of the cut-waters, which project 4 feet beyond it. The roadway is 37 feet 9 inches wide between the rear parapet and the up-stream front windlasses; it acts as the main line of communication between Hurdwar and Kunkhul.

97. The design of Shutter for closing the regulators is different to that which has been practised on the Jumna canals; it affords much greater facilities for working, and secures either the closing or the shutting of the bays in a much shorter period of time.

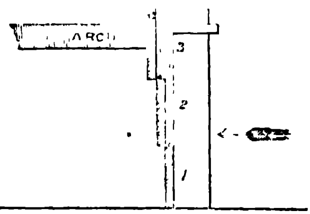
On the Jumna regulators, a drop gate is used in a simple groove, and sleepers with a scantling of 6 inches square are dropped upon the top of the gate. Both time and labor are required to close or open the bays when fitted with apparatus of this sort, but it has always acted very efficiently; and opposed to the Jumna floods, has done its duty very well. On the Jumna canals, however, there was not the same volume of water to contend against, nor the same number of bays to open and shut, that exist on the works which we are now describing; and it was necessary, with ten bays upon which the safety of the works depended, to devise some quicker method than that which acted for three, and, if possible, to economize the labor required for using the apparatus. The following diagrams will show in vertical section the method which is in use on the Jumna, and the improved method which was adopted in the present case.

Fig. 1.



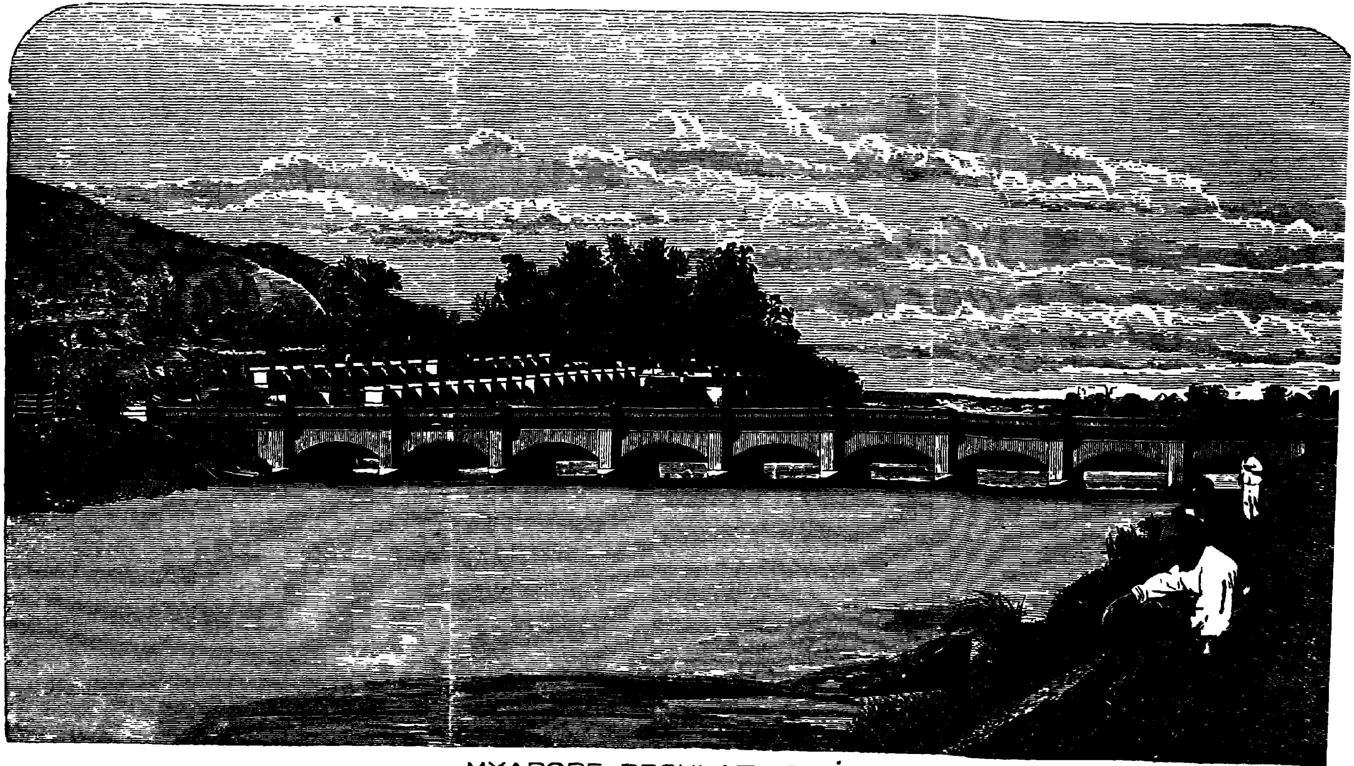
Old Method on the Jumna.

Fig. 2.

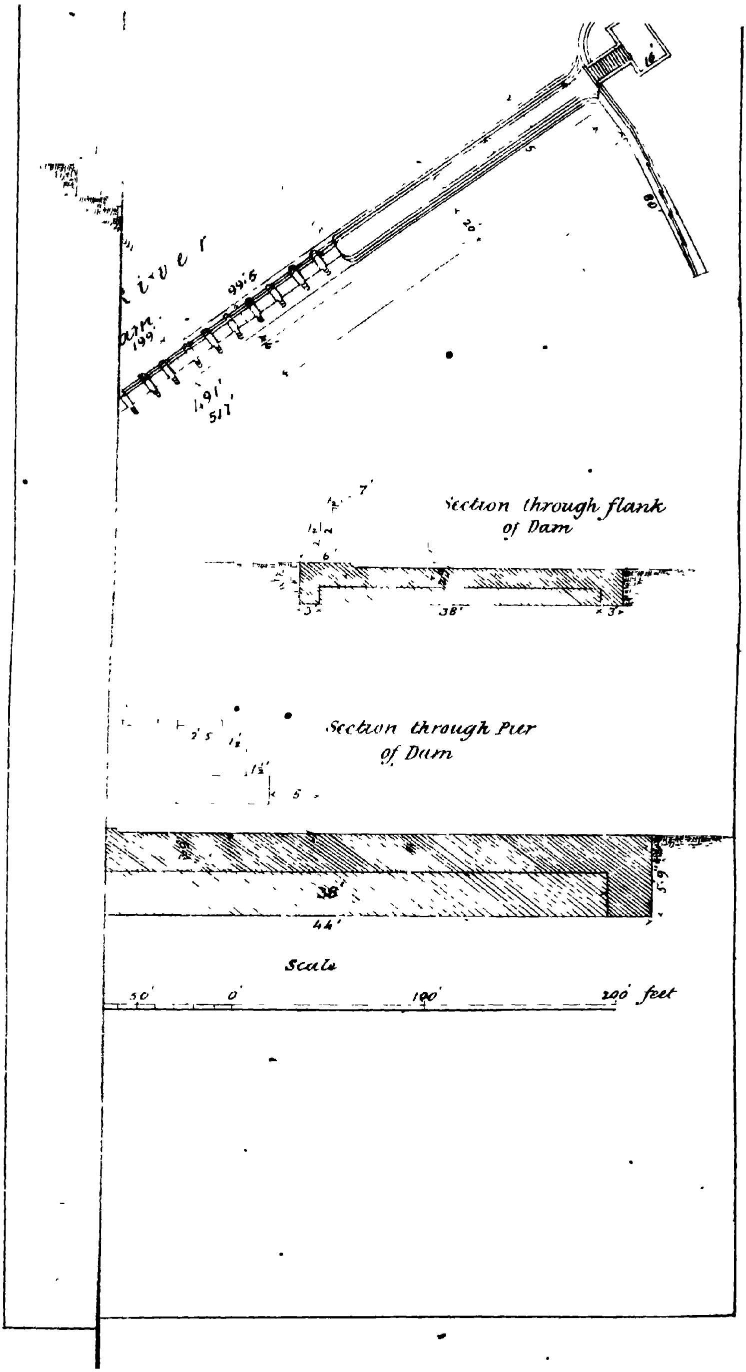


Improved Method on the Ganges

Fig. 1, it will be observed, represents the groove and its cutwater opposed to the



MYAPORE REGULATING BRIDGE.


Section through flank of Dam
38'
Section through Pier of Dam
38'
44'
Scale
50' 0' 100' 200' feet

up-stream current; *a'* represents a gate 5 feet in depth, which is kept suspended in dry seasons and is dropped down on the expectation of flood; *b, b, b,* show the sleepers or long bars of timber, which when the chains are removed from the gates, are successively dropped upon them until the bay is closed. The time that this takes is equal to eighteen minutes.

Fig. 2 shows the improved design, gained by the use of two windlasses. The bay or opening, it will be observed, is divided into three series, the more advanced one having its sill on the zero level; the centrical and rear ones having their sills elevated in heights of 6 feet, retrograding towards the face of the bridge. The shutter marked No. 1 is dropped from a windlass on the bitt-head 1; that marked No. 2, from the bitt-head 2; that marked No. 3 consists of sleepers, which are raised and lowered without the aid of a windlass. The three gates, therefore, are quite independent of each other; each has its own sill to rest upon; and the whole can, if *necessary, be worked simultaneously. The great advantage of this method will be understood, by supposing that a supply of water not exceeding 6 feet in depth* is required for canal purposes. In this case, the whole of the shutters *2 and 3 may* remain closed; and when floods come on, the whole of the water-way may be stopped by releasing one set of gates only.

The machinery attached to these gates is of the most simple description, intelligible to the commonest laborer on the works, and not liable to disarrangement. It consists of windlasses, which work in sockets embedded in wooden bitt-heads, with ratchet wheels and catches; the windlasses being turned by hand-spikes. The chains are on the bar principle, in lengths of 3 inches, with plain rivets; and the shutters are mere planks, strung upon iron rods, held at their lower ends by nuts, and terminating above by rings countersunk for fixing the chain upon. The wood used is sál (*Shorea robusta*), the staple timber of the Sewalik forests.

98. The above description may be understood to apply to all regulators employed on the canal, as well as to the one at the head. Thus there will be a double regulating head where each branch is taken off, one regulator being fixed across the head of the branch line to admit the necessary amount of water which the branch is calculated to hold, and the other being built across the main channel at the same spot By the simultaneous working of the two it is evident that the water will be perfectly controlled.

Regulators of smaller size will also be required at the head of each *Rajbuha* or principal water-course, where it is taken off from the main line for irrigating purposes. A single opening will generally be enough, and gates sliding up and down in the grooves of the abutments may be worked by a ratchet and lever, or a windlass with spokes.

99. But in order to establish a complete control over the water in the canal channel, provision must be made for any excess which may arise from sudden rain floods or from the water not being always required for irrigation. This is effected by means of *Escapes*, which are short cuts

from the canal to a river or other natural water-course, into which the excess of water can be discharged. Escapes it has been well said, are to a canal what safety valves are to a steam engine. They should be provided at certain intervals all the way down the line, and a double regulating head should be built at the point where the escape is taken off, as in the case of a branch canal. On the Ganges Canal they were projected at about every 40 miles, but much must depend on the convenience with which they can be made, that is, on the proximity of the canal to the river or water-course into which the escape is to be conducted. They should also, if possible be provided at all dangerous points, such as above a long line of heavy embankment, where, in case of the bank bursting, great damage would ensue. The cut should be made large enough, and with sufficient fall, to carry off the whole body of water that can reach that point, so if necessary, the canal below the escape may be at any time laid dry for repairs, without stopping its running above—by opening the escape regulator and shutting down the corresponding one across the canal. By this means also that part of the canal above the escape may be opened when completed, while work on the lower portion can proceed.

100. The following is a description of the Khutowli Escape Head on the Ganges Canal, at the 62nd mile, the escape itself being an excavated channel 60 feet wide at the head and $3\frac{1}{2}$ miles long:—

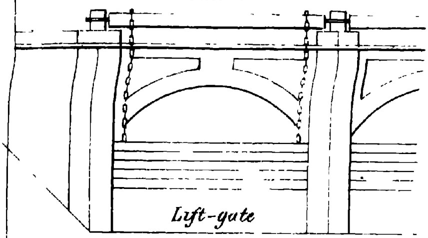
The masonry head consists of 10 openings of 6 feet in width each, their height from flooring to the soffit of the arch being $8\frac{1}{2}$ feet; the flooring is raised 2 feet above the canal bed in gradations depending on the working of the gates and sleepers. The transverse width of the flooring is equal to 64 feet, 40 of which form the tail which is laid on a slope (including down-stream) of 1 foot from the level of the canal bed. The flanks of this work are protected by masonry revetments, and the usual guards of piling and rubble work, with which the floorings are also covered and protected from the wear and tear of the current on its approach and departure, by box-work aprons.

In consequence of the magnitude of the canal embankments at Khutowli, and the elevation of their upper esplanade, which is $20\frac{1}{2}$ feet above the canal bed, the apparatus for opening and shutting the sluices has been covered by a line of building, the roof of which corresponds with the higher levels, and, therefore, acts as a roadway without interrupting the communication on the bank. The supports for the windlasses, which consist of upright timbers placed in the form of a cross, act also as supports to the roof, and give great additional strength to the building. It will be seen by the plan, that the chains attached run over an upper roller, by which the whole water-way is relieved, by the gate being drawn up through the slit made in the flooring, and raised as high as the roof.

CANAL REGULATING APPARATUS.

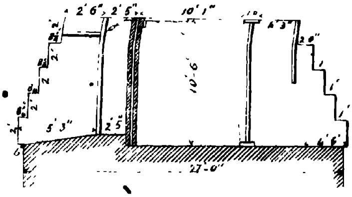
Regulating Bridge with Lift-gate & Sleepers.

Elevation

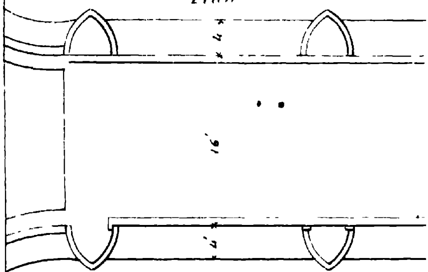


Drop-gate for Dams

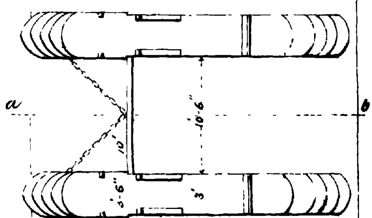
Elevation



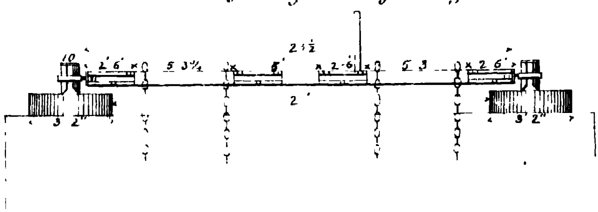
Plan



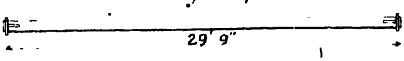
Plan



Windlass for Regulating Bridge.

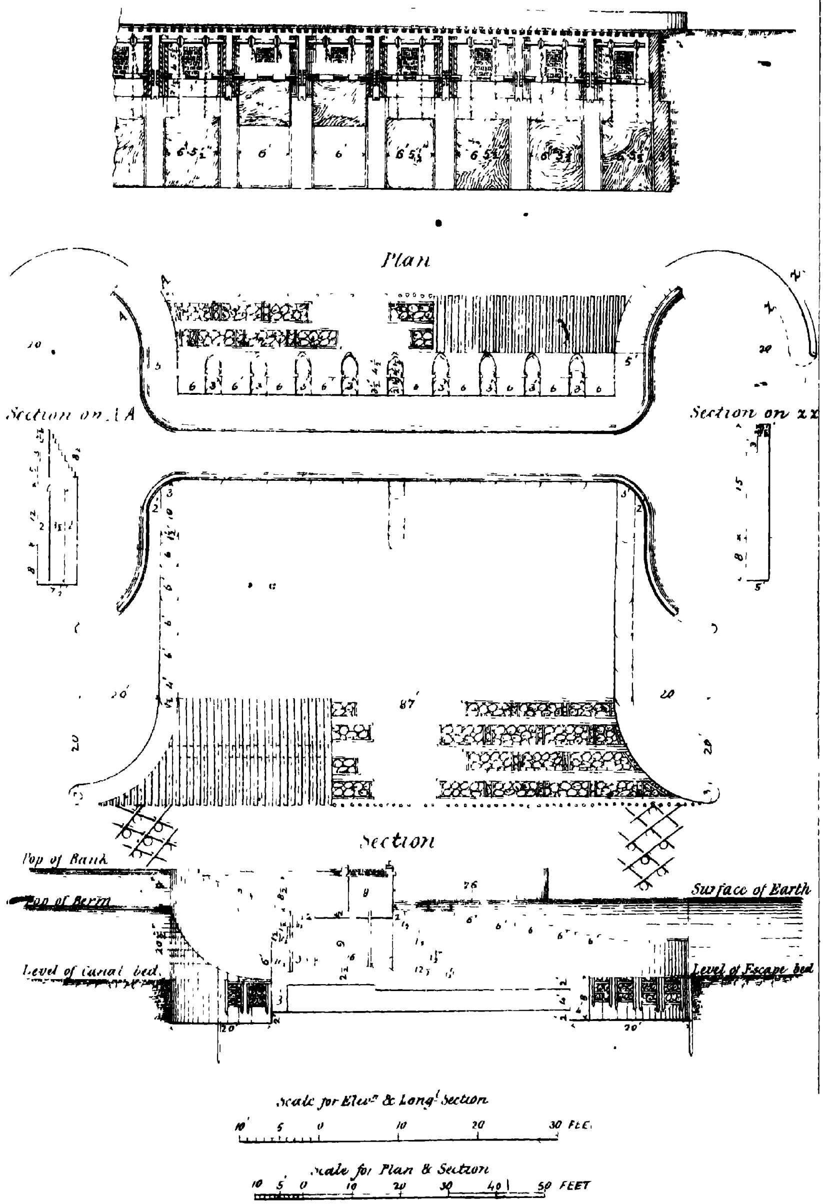


Plan of Sleeper.



KHUTOWLI ESCAPE HEAD
GANGES CANAL.

Elevation and Longitudinal Section
Interior of the Khutowli Escape



CHAPTER VII.

RAJBUHAS—MEASUREMENT OF WATER—IRRIGATION DETAILS.

101. THE distribution of the water, it has already been explained, is effected by means of *Rajbuhas* or distributary water-courses, which are small branch canals with a masonry regulator at the head, from which the cultivators make their own water-courses to their fields. On the older canals, irrigation was carried on from the main channel itself, the water-courses being constructed by the Zemindars; but the inconveniences arising from this practice were found to be so great, arising chiefly from waste of water, that the rajbuha system is now generally adopted. In this system we may, as Sir Proby Cautley remarks, consider the canal as answering to the Reservoir or supply channel in the water-supply of towns; the rajbuhas or distributaries as the Mains, and the village water-courses as the Service channels.

The rajbuhas are laid out by the Canal Engineers, and are under their exclusive control for maintenance and repair; on some of the canals they used to be the private property of the Zemindars, who either advanced the money for their construction, or repaid it to Government if (as was generally the case) it had been made with Government funds in the first instance. But it is in every way desirable that the rajbuhas should be considered as part of the first cost of the canal, even if a higher water-rate has to be charged to cover the expense of their construction.

102. In order to deliver the water under the most favorable conditions, it is clear that irrigating channels must everywhere follow the water-sheds of the country drainage. The first step then is to ascertain how many features of this kind exist, their extent and relative situations. This knowledge can only be acquired from a careful survey of the country it is designed to irrigate, care being taken to delineate on the map the course of all rivers, nullahs and streams, and the position of all hollows and jheels. To each watershed should then be as-

signed a separate channel of capacity apportioned to the duty it has to perform, the two bounding streams or nullahs being considered in this system as the limits to which irrigation from any single line should be carried.

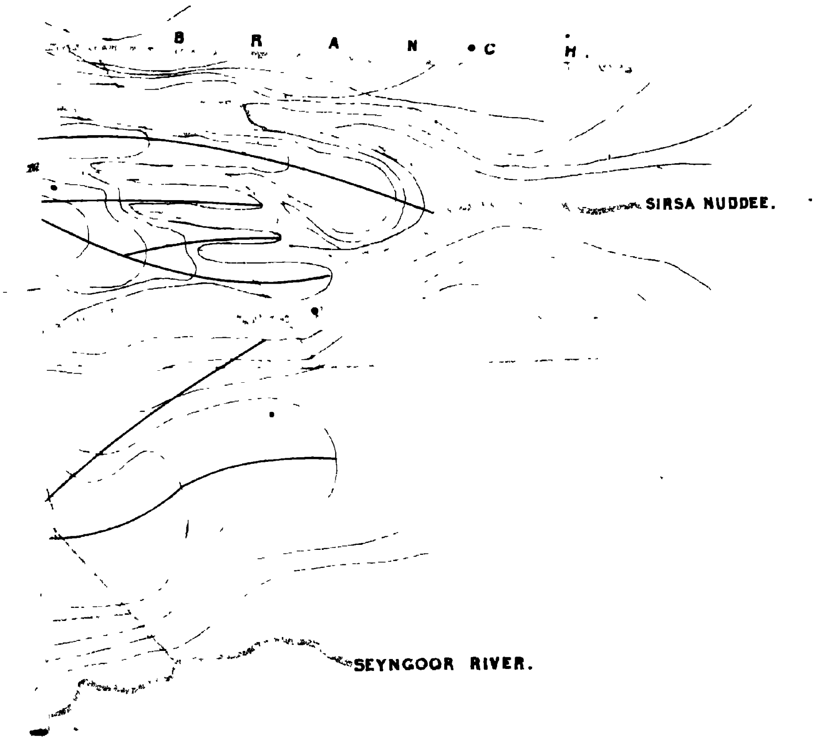
Having then traced out on the drainage survey map the general course of the proposed channels, it is necessary to run a series of cross levels in order to fix the exact position of the watershed. With the aid of the information thus obtained, the Engineer will be enabled, *after a careful examination of the ground*, to fix on the precise trace of the proposed lines.

103. For the more complete and efficient distribution of the water, branch lines (or minor distributaries), should be taken out from the main or principal channels where they may be most required; but the Engineer should in a measure be guided by the nature of the ground and the character of the soil. As in the case of larger works, he should endeavour to secure a command of level for the purpose of affording every facility for irrigation: he should avoid as far as possible crossing minor drainages or stumbling into hollows by which his object may in any measure be defeated: he should banish from his mind any idea he may entertain of the relative unimportance of this class of works; for he may be assured that nothing tends so directly to an economical distribution of the water as a carefully constructed system of minor rajbuhas.

Thus a principle is established which is susceptible of universal application, whether the works to be designed are of the greatest magnitude or of the smallest pretensions. Though sufficiently understood in the alignment of large canals, it has been too much ignored in the projection of minor channels, to which must in a great measure be attributed the difficulties that attend the distribution of the water.

In the system advocated above, the capacity of an irrigating channel should everywhere be exactly apportioned to the duty it has to perform, the section decreasing as the line advances, until it loses itself in a small village water-course. A large margin should be allowed for further possible development of irrigation.

104. Escapes will be required at every 8 or 10 miles, but they should only be resorted to on emergencies, it being preferable to reduce the supply by partially closing the gates at the head.


B R A N C H.
SIRSA NUDDEE.
SEYNGOOR RIVER.

A very important consideration which has been neglected with the most serious consequences is, that the natural drainage lines into which an escape debouches should be large enough to carry off at all seasons the water let suddenly into it without causing flooding. In the plains of Upper India, the "nuddees" or natural drains are often narrow tortuous channels cultivated to their very edge in the cold weather, or right across their bed. This is just the season when the rajbuha escape is most needed, when sudden rain storms come on in the full tide of irrigation, and letting a sudden influx of water into these lines, has caused very serious damage both in the Eastern Jumna and Ganges Canals. The result is that many rajbuha escapes constructed at some expense are now *never* used, and of seven large expensive ones constructed by Sir P. Cautley between Roorkee and Mynpoorie on the Ganges Canal itself, only one is of the least use.

105. The level of the bed of the rajbuha should be fixed rather with reference to the full supply level of the canal than to the level of the canal bed, chiefly because it is an object to keep the rajbuha bed at a sufficiently high level to admit of surface irrigation on its whole line as far as possible. Moreover, the nearer from the surface that water is taken off by a rajbuha head, the less will be the silt which enters the rajbuha and the less the annual labor of clearing the bed. The bed of a rajbuha will, therefore, generally be from 1 to 3 feet higher than that of the main canal.

The slope of a rajbuha bed ought to be as nearly as possible parallel to that of the district it traverses, in order to avoid costly and useless embankments on the one hand, and to ensure on the other that the surface of the water shall always be above that of the country, and *flush* irrigation shall be possible. In most soils a velocity of 3 feet per second is not too great, or a slope of 2 feet per mile; while in flatter country, rajbuhas are successfully worked with a slope of bed not more than 6 inches to the mile.

If *falls* are rendered necessary by the profile of the country, they must be provided on the same principle as those on the main line, and it is even advantageous to have one at the point where one rajbuha tails into another, to get rid of back-water and prevent the accumulation of silt.

106. When rajbuhas cross roads, the latter may either be provided with bridges or the former may be passed under the road by a *Syphon*

often with a great saving of expense. Plans are given of approved forms of syphons which sufficiently explain themselves.

107. Rajbuhas may be cleared of silt whenever the water is least required. One, or at the most two clearances a year are enough for a well designed rajbuha. The floorings of all bridges and other masonry works, built over them, will of course have been carefully laid down to the proper levels, and will give so many permanent bench-marks for restoring the correct level of the beds; besides which, stakes or masonry bench-marks should be fixed at intervals, not exceeding a furlong.

108. The* greater the amount discharged by a rajbuha the smaller will be the proportion of cost of maintenance to the revenue derived. This is evident, when we consider that, "*cœteris paribus*," a channel 12 feet wide discharges more than double the volume delivered by two, each 6 feet wide, and consequently has more than twice their irrigating capacity, while the cost of patrolling and repairs to banks on the first will be just one-half that on the two last. The carrying powers of large volumes of water being also greater, the deposit of silt in the 12 feet rajbuha will be more gradual than in the 6 feet channels, thus doing away with the necessity of frequent clearances. The actual amount of clearances during the year is also diminished, for a great portion of the silt which would be rapidly deposited at the head of a small line, is carried along and dropped into the water-courses branching off from a large one. The labor of clearance is thus in some measure thrown on the cultivators, who would have to pay for it in any case, but by whom it is much more cheaply performed than by the Government working parties. For the above reasons, Major Brownlow advocates the adoption of capacious heads for rajbuha channels, the limit of discharge being the ability to control the volume of water in case of a breach.

109. Experience seems to prove that irrigation may be safely and most profitably carried on from channels 18 feet wide at bottom, with side slopes of 45°, depth of water being 3½ to 4 feet, provided that the bed be kept at least 2 feet below soil for the first ten miles of its course, and that no outlets be allowed in subsequent embanked portions of the line. On the Eastern Jumna canal during 1858-59 and 1859-60, the revenue from all rajbuhas of 12 feet head water-way and upwards

* This paragraph is taken from a Memorandum by Major Brownlow, R. E., late Superintendent of the Eastern Jumna Canal.

amounted to rupees 1,29,618·76, while the expenditure on their maintenance was rupees 16,038·05, or ·123 of the revenue. The revenue from all rajbuhas *below* 12 feet water-way at the head was rupees 2,67,049·83, and cost of maintenance, rupees 56,579·87, or ·223 of the revenue, being very nearly double the proportion in the first case.

110. The economy of water on the large channels is equally marked, for during the above-named two years, we find the revenue from

7 rajbuhas of	12 ft.	head water-way and upwards,		Rs.	1,29,618·76
49	”	6 ”	”	”	”	2,16,432 86
29	”	3 ”	”	”	”	50,616·97

giving an average revenue per annum of

Rupees	9,258·48	from a rajbuha of	12	feet head water-way.
”	2,208 58	” ”	6	” ”
”	872·70	” ”	3	” ”

Measurements made in 1855 gave 86, 32, and 22 cubic feet, as the relative discharges in cubic feet per second from 12 feet, 6 feet, and 3 feet, heads on this canal; but subsequent measurement suggested a modification of the proportion to 90, 32 and 22; adopting which, we have as the relative values of a cubic foot of water per annum—

Rupees	102 87	on	12	feet rajbuha.
”	69 50	”	6	” ”
”	39 65	”	3	” ”

or 10 : 7 : 4.

The increased action of absorption and evaporation on the small channels, with diminished volumes and feeble sluggish currents, accounts for the difference above shown.

111. The *depth of water* in rajbuhas should seldom exceed 4 feet; but in carrying out a new line of irrigation, we should aim at keeping the surface of water at about 1 to 1½ feet above the general surface of country, so as to secure irrigation by the natural flow of water. Under these conditions, breaches in the banks need never be feared, with ordinary care in their construction and maintenance. This object, however, is to be kept in due subordination to the primary desiderata of a reasonable longitudinal slope, and an alignment following the watershed of the country.

Where the existing supply on a rajbuha becomes insufficient for the demand, it will be, in the end, found more economical to increase the discharge by widening the original channel for a suitable distance, than to do

so by carrying the required additional volume down from a second head as used to be often done; against the latter course, all the arguments before adduced hold *good*, while the back-water from the head which is running the strongest, is sure *to check the velocity of water in the other, and so* immensely accelerate the deposit of silt.

112. The system of raising water to the level of the country, where it runs below the surface of soil, by *stop dams* or *planks*, introduced into grooves constructed for the purposes, cannot be too strongly condemned. These convert what should be a freely flowing stream, into a series of stagnant and unwholesome pools, encourage the growth of weeds and the deposit of silt, and are in every way objectionable. Besides, with a reasonable slope in the surface of the country, it will be generally found that, for every beegah of irrigation thus secured, ten can be obtained further on by the natural flow of water. Be this, however, possible or not, it is decidedly better to resort to any other means of raising the water to the level of the country than the above wasteful and unhealthy expedient.

113. The cost of rajbuha repairs on the Ganges and Eastern Jumna Canals varies according to circumstances from about 50 to 30 Rs. per mile. The cheapest maintenance hitherto on the Ganges Canal in proportion to acreage watered was in 1868-69, when it was ·7 rupee; this included both canal and rajbuha maintenance and repairs.

114. The village water-courses receive water from the rajbuha by means of *kolabas*, which are long wooden* tubes, with a rectangular or triangular transverse section of fixed dimensions, running under the rajbuha banks, being closed when required by a sliding wooden shutter. They should be fixed rigidly in a horizontal position and at right angles to the rajbuha bed; the bottom of the kolaba being slightly raised above the level of the latter.

The *Irrigation outlets*, or "*kolabas*," on the Eastern Jumna canal are of two kinds.—"Full," measuring 8″ × 10″ (the latter dimension being vertical); and "half," measuring 8″ × 5″. [These dimensions are now generally looked on as too large, 20 to 30 square inches being considered enough.] The conditions of discharge vary indefinitely with each outlet, but 2 cubic feet may be assumed as the average volume delivered by a full, and one cubic foot as that delivered by a half, kolaba per second.

* Whenever possible the tube should be of more lasting material than wood. Earthenware pipes set in concrete, with masonry ends, are now largely used. The question of the best style of kolaba is still an open one.

Kolabas on the Eastern Jumna canal were formerly placed at various heights above the rajbuha bed, diminishing from 1 foot near the head to 3 inches or less, at the tail, with the view of equalising, in some *measure, the head of water on each. But, in practice, this plan was found most inconvenient,* as during periods of small expenditure of water, it became necessary to run nearly a full supply in rajbuhas to give the kolabas at the head any water at all, and the channels at the tails of long lines became so gorged that breaches in the banks were sure to ensue.

Besides, the exterior conditions of discharge vary so much as to nullify in a great measure all interior arrangements. The outlets are, therefore, now built all flush with the bed, by which means the irrigators at the head can obtain water with a low supply in the rajbuha, and any extra advantage thereby gained can be compensated for by longer "tateels" when necessary.

115. When the supply entering the head of any irrigating channel becomes insufficient for the demand, it is necessary to distribute the water fairly by closing or diminishing the supply entering the outlets near the head for a certain time, and thus forcing it down to the tail. Such a closing of outlets is known in the N. W. Provinces as a "*Tateel*." It is better not to impose a "tateel" on rajbuha heads, but to regulate the supply entering them according to the demand lower down the canal. The advantages of a constant but moderate supply in rajbuhas are, that embankments are kept moist and are thereby less liable to crack and be breached by water, and that the growth of grass and weeds in the bed is checked.

Where tateels become an established custom, as they must do on every fully developed system of irrigation, it is advisable to impose them over long portions of a rajbuha at once, and to fix certain days of the week for their maintenance. Short lengths of tateel have very little effect, besides being nearly as troublesome to watch as long ones, and zemindars will remember days of the week who cannot be brought to recollect dates. On the Eastern Jumna canal, notices of tateels are given to irrigators, who close their kolabas of their own accord at the appointed time. On long lines, the outlets on the first length (near the head) are closed for four days of the week, and on the second portion for three days, thus ensuring a permanent, though moderate

supply to those at the tail. Notices of tateel ought always be given to the *cultivators, and changes made as seldom as possible. Many* rajbuhas can only be allowed to run during alternate weeks.

116. Field irrigation is known as "flush" or "lift" (*Tor* or *Dál**) according as it is, or is not, surface irrigation. In the former case, the water flows over the fields through cuts in the banks of the water-course, which are then closed. In the latter case, it is raised or thrown on to the land, usually in a primitive manner by men with shallow swing buckets and ropes. Of course less is charged for water supplied to land where the levels do not admit of *flush* irrigation.

117. *Water-rates* are assessed on the area irrigated, and vary according to the nature of the crop and the amount of water it requires. A separate arrangement and payment is either made for each harvest, or a contract is made for a certain number of years. The measurements are made by the Canal Officers, and the amount due by the different villages is recovered by the Collector of the district.

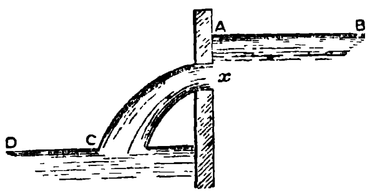
Over every 20 square miles or so of an irrigated district there is placed an *Ameen*, whose duty it is to keep constantly traversing his beat and noting how the irrigation is progressing. To help him he has copies of the *Shujrehs* and *Khusrehs* of all the villages under him, the former being maps of the lands showing the position of every single field and its number, the latter a record of the area of each field, and its owner. When the crop is about half grown, or earlier, the measurements commence. A fortnight's notice is given to the Collector of the district, and he issues orders for the presence with the measuring parties of the *Putwaries* of the villages. The cultivators also get full intimation, and the measuring party consists of the canal *Ameen* and *Chokedar*, the village *Putwaree* and *Lumberdar*, and the cultivators concerned, while the zillahdar keeps constantly visiting one of the parties in his zillah. Field after field is visited, its place and number found in the map, its area and ownership in the *khusreh;* the crop grown on it is noted, and the fact whether the irrigation has been *flush* or *lift*, the water-rate for the latter being one-third lower than for the former. From the field-book thus compiled, is made out a statement bringing together each man's fields and showing what he has to pay for his irrigation. This is termed the *Khuteonee;* it is made over to the

* *Torna* to break (the bank); *Dalna* to throw (the water).

Putwaree, and lies for a fortnight in the village open to the inspection *of all, after which the village Lumberdar* collects the water-rate and deposits it in the nearest Government treasury.

118. It is clear, however, that the fairest method of charging payment for water is to sell it as one would sell any other article; that is, according to the quantity taken. It cannot make any difference to the canal proprietor what becomes of the water after he has once issued it and been paid for it, and to have to enquire to what purpose it has been put before he can fix or receive its price, is naturally productive of vexatious interference, and unnecessary expense and delay. Unfortunately, however, the difficulties in the way of delivering water by measurement have hitherto been found insuperable, chiefly because no practical method has yet been hit upon of measuring the water under a head of pressure constantly varying; for, not only does the surface level of the water in the main channel continually change according to the amount of water taken off above, the amount of rain-fall, &c., but the deposits of silt at the head of the distributing channel would also cause the quantity discharged to vary continually.

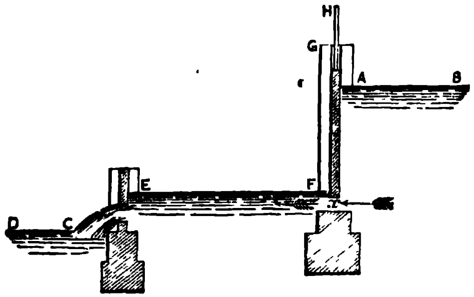
119. The ordinary form of orifice through which water is discharged for irrigation is rectangular or circular, the orifice being set vertically in the side or end of the channel forming the source of supply. Thus, if AB represent the level of water in a canal, and x an orifice through which that water issues, as long the level is uniform the cultivators will receive an uniform supply. Let us suppose a cultivator pays for a continuous discharge through an opening with the water standing in the source of supply one foot above the centre of discharge x. In other words, his contract is for his orifice to remain open, and for Government to maintain the supply at the depth Ax, or one foot.



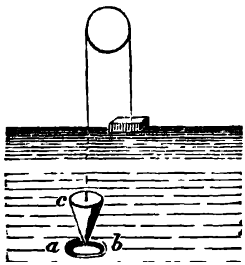
Now, the velocity with which a fluid issues from an orifice varies as the square root of the depth of the centre of discharge of that orifice below the surface of such fluid. In the case of a small orifice, its true centre and its centre of discharge may be taken practically to be the same. Therefore, should the surface level instead of being one foot above x,

happen to fall 9 inches, the cultivator would receive merely *half* his due, whereas that level must rise 3 feet, or four times the preceding amount, to give him *double* his due.

120. What the Italians have done to obtain an uniform discharge, as explained by Colonel Baird Smith, may be summed up in very few words. *Instead of irrigating directly from the source of supply, they make use of an intermediate chamber*, EF; AB being the source of supply, the water is retained by the wall G, which is fitted with the lifting sluice-gate Hx. This sluice-gate is lifted or depressed by hand, so as to maintain the water level EF, in the next chamber, uniform, and at the standard level, and *as long as this is done, and there is a fall out of the chamber EF, the cultivator gets exactly what he pays for.*



This apparatus, however, is very imperfect. It only mitigates the evil mentioned above, and affords no protection against the carelessness or dishonesty of the officials, whose duty it is to work the sluice gate Hx, raising and depressing it as the head pressure of water in the canal varies. It has, however, the practical advantage of enabling the cultivator to satisfy himself that he obtains his rights more easily, by watching the water level EF, than by examining the height to which the sluice Hx is lifted; to do which, to any purpose, he must understand, and have access to, the information possessed by the canal servant regulating the discharge.

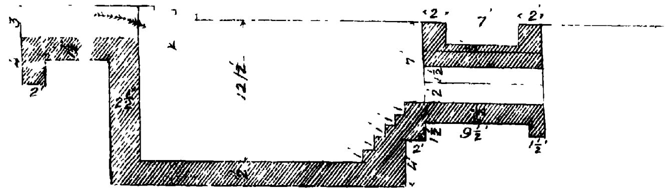


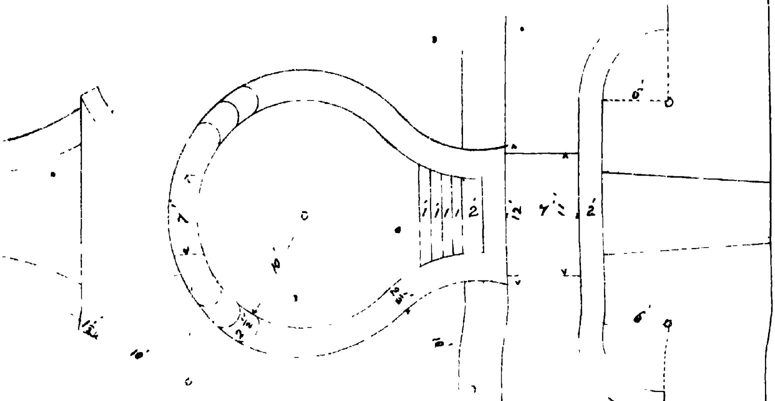
121. It is evident that to give an uniform discharge, contraction of the orifice or waterway must take place in proportion as the depth of water increases. And Col. Goodwyn proposes to employ a cone fitting into a circular orifice, which by means of a pulley and balance float should sink as the water rises and rise, as the water sinks, so as always to allow the

DETAILS OF

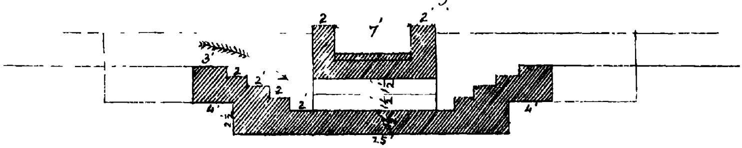
As designed for the Soane Canals.

Fall on a Distributary with aqueduct over tail.



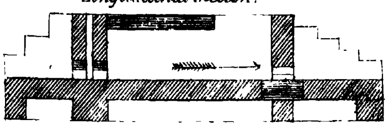


Syphon Drain for passing one Distributary under another or under or over a drainage Channel

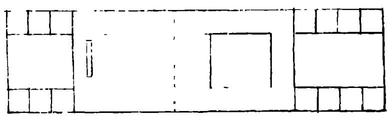


Village water-course Head for measuring the water with-drawn from the Distributary

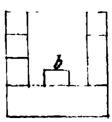
Longitudinal Section.



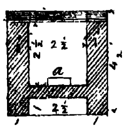
Plan over all



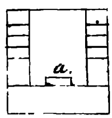
Head Elevation



Centre Cross Section

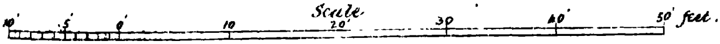


Tail Elevation.



Opening a = 12 × 4.16" to discharge 1 cubic foot per second under a head of 4 inches

Scale



same amount of water to flow through the annular space round the cone. This is the principle adopted on the new Canal of Isabella II., near Madrid, (*see* Capt. Scott Moncrieff's Report, pages 12, 13,) but whether that canal has yet been opened or not is not known.

122. In the original project for the Soane canals, the rajbuha heads and village water-course heads are on the plan of the Italian module as described above, *i. e.*, to reckon the water by the discharge under a given head, which is known by the ordinary hydraulic rules, either (1) when the discharge takes place freely into the air, or (2) when it is simply a descent from an upper to a lower level.

The latter method is the one proposed. In both cases, the front sluice board is used to admit such a supply as shall just keep the level of the water in the interior chamber at the mark denoting the desired head of supply. But on the village water-course heads, it would be impossible to supervise the working of the head sluice board. It can only be used to shut off the supply when the water is not required. The level of these water-course heads must be so placed that when the intended supply of water is passing down the rajbuha, every village water-course may just have its proper supply, as contracted for. The regulation must be attempted only at the rajbuha head, and the Government will lose a portion of the tail surplus, and the other villages or cultivators gain it, when one or more villages or cultivators let their modules remain closed.

123. The following is a description of a new water Module, invented and patented by the late Lieut. Carroll, R.E., which has lately been tried on the Ganges Canal, with partial success.

To the mouth of the kolaba a valve is attached of the form and dimensions shown in the Plate, and which may be made of brass or iron.

Its mode of action is very simple. When the plate which hangs in front of the tube is down, the quadrant which is attached to it is at its highest point, and it will be seen that a free water-way exists through the tube and between its under lip and the plate in front. If the plate be raised, the quadrant sinks into the tube, and reduces the water-way in proportion to the angle through which the plate is raised.

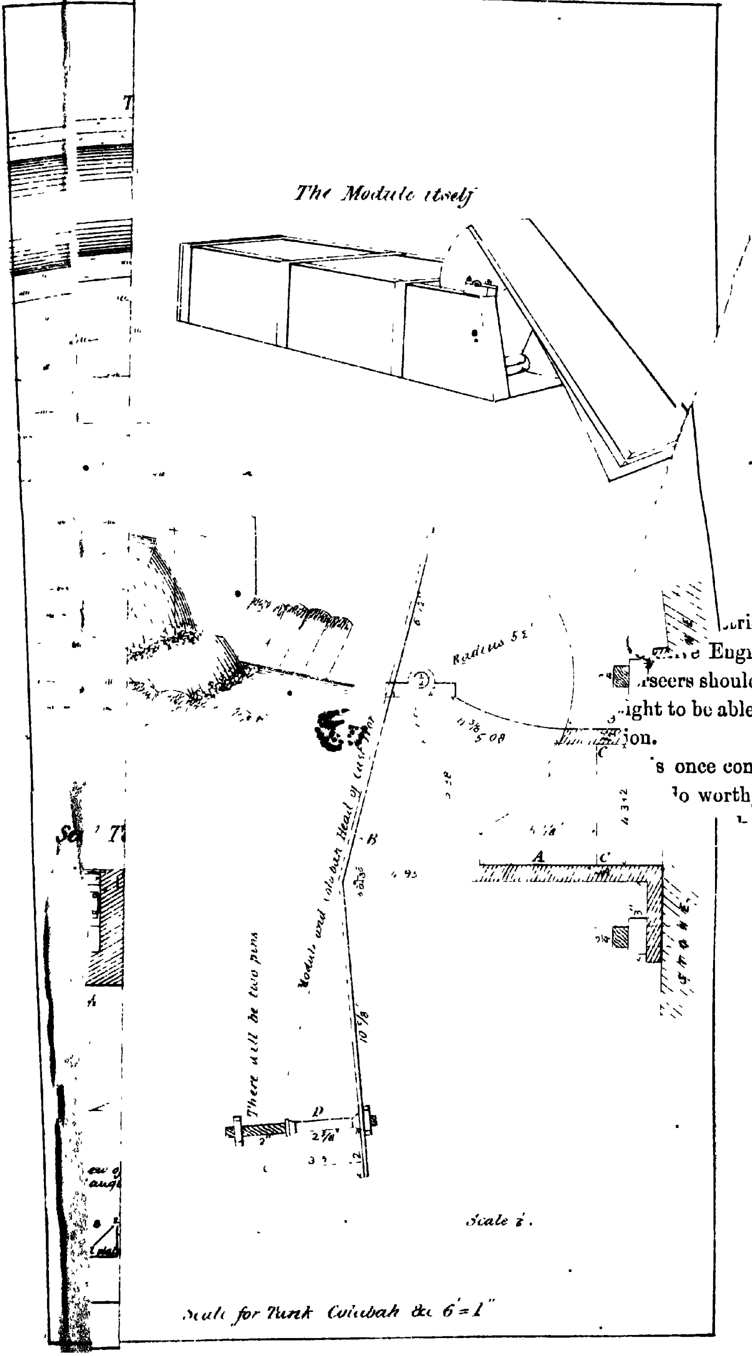
Now, if it be desired to obtain an equal discharge while the head of water in the canal varies from 3 feet down to 1 foot, the plate is weighted so that the force of the issuing stream at a 1 foot head shall be just unable to move the plate outwards. As the head rises above this, the velocity of the stream becomes greater and drives out the plate, thus reducing the water-way till, at a 3 feet head, the plate will remain at a very high angle, and the quadrant will close a great part of the water-way of the tube. The curve of the plate is so adjusted that it shall rest at such an angle as to give the same discharge as at a 1 foot head ; when this is done, it is found that, at all

intermediate heads, the discharge remains almost the same. Experiment gives 1 per cent. as the ordinary deviation from exact equality. This module can be equally well applied to regulate under lower heads, such as from 1 foot to 3 inches, but requires lighter weights and some other simple adjustments.

The merits claimed for this module are simplicity, cheapness, non-liability to derangement or choking, and the ease with which it can be protected from injury by enclosing it in a small masonry or iron chamber.

124. The disadvantages of area payment are so serious, that the system of water measurement by discharge will no doubt be generally introduced before long in some form or other, care being taken to leave a liberal margin in favor of the Zemindars; and on the longer established Eastern Jumna Canal, a system of contracts based on averages of past years is worked with perfect success, and is probably the true solution of the problem.

PLATE XIX.



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CHAPTER VIII.

DUTIES OF CANAL ESTABLISHMENT.

125. The establishment of a Canal Division in the N. W. Provinces consists generally of the following:—The Executive Engineer, assisted in Revenue and Judicial matters by a Native Deputy Magistrate and *Zillahdars*, and in constructive details by Assistant Engineers or Upper Subordinates, with Sub-Overseers under them again. The *Ameens* are directly under the zillahdars for conducting the measurements, and the charge of the main canal and its distributaries is divided among a number of patrols or *Chokedars*. The distinction between the Revenue and the Engineering branches of work is, however, never clearly divided. The Assistant Engineer ought to be most valuable in assisting in water distribution and management, having occasionally, like the Executive Engineer, the powers of a Deputy Magistrate, and the Sub-Overseers should all assist in the same way, while the Deputy Magistrate ought to be able, when required, to take temporary charge of a Sub-Division.

126. It is too commonly supposed that when the canal is once constructed, there remains little for the Executive Engineer to do worthy of a man of any ability or education. This is a very great mistake. There may be no great works left to construct, but there are sure to be many small ones requiring much experience and precision to execute properly. There are many points of the purest science still undetermined, such as the true formulæ for the discharge of large bodies of water in open channels or over weirs,—the amount of loss by percolation and evaporation,—the effect on the velocity of a stream of a large percentage of silt carried along. The Executive Engineer may have besides, to train and do battle with rivers of great size, or the not less troublesome hill torrents, such as issue from every valley of the Sub-Himalayan ranges. He may have in his charge a series of weirs which have to be constantly watched and protected, while repairs, often of the most important charac-

ter have to be executed within the space of only a few days when the canal can be closed. Alongside of his weirs he may have locks to superintend. His rajbuhas ought to be a source of constant interest, requiring extension and improvements, while he will find, as he goes on irrigating, that drainage has to be attended to and artificial cuts to be laid out, to correct the over-saturation which only the best administration can prevent from taking place, and to ward off the malaria which over-saturation produces.

Besides all this, no man should consider it beneath his attention to *exercise almost independent control over a large body of water, bringing in a revenue every year perhaps of 4 or 5 lakhs of rupees, (the Eastern Jumna Canal* revenue exceeds 6 lakhs,) and being a source of wealth to the country of at least four times that amount.

He must be perpetually on his guard against the chicanery that is sure to be rife amongst his subordinates. He is invested with certain magisterial powers. He should possess a general knowledge of the agriculture of the district, and know at what seasons the various crops most want watering, and what soils most require it. If he is fond of forestry, he will have room for gratifying his taste in cherishing and extending the plantations along the banks of his canal, and may (as Sir Proby Cautley did) render lasting benefits to the country by the introduction of new trees. Among lesser matters, he may turn his attention to utilizing the water power of his canal, a subject which must claim attention as the country progresses. If the above subjects do not possess sufficient interest for the Engineer, he had better choose some other line than the irrigation department. Nor ought he to look for employment on a running canal if he is not prepared for a life of constant moving about at all seasons of the year. He must expect for little of the pleasures of society or domestic life, and be prepared for many a long hot day by himself in the canal inspection houses.

127. The Assistant Engineer aids more or less in all the above, but his first duty is to carry out the execution of all works, whether original or repairs, within his Sub-Division. He is responsible for the measurements of earthwork, masonry, &c., done; he has special charge of all the stock of building materials, plant, &c. He submits, in the first week of each month, detailed accounts of all manner of expenditure, and keeps with his own hand a precise cash-book of all payments. He

ought to know exactly the *tateels* on his rajbuhas, and help in checking the measurements of irrigation.

128. The first duty of the Native Deputy Magistrate, as his name denotes, is the trial of offenders against canal law, but he occupies a most important place besides in settling disputes about water, superintending all the irrigation measurements, and he should bring to the Executive Engineer's notice any irregularities which he finds in the Division, which as a Native he can often detect far more than any European. If besides this he bears the high character for probity and truthfulness that more than one of his class holds, he will be constantly referred to as an arbiter among the cultivators, and be a most valuable help in making the canal administration popular.

129. The *Zillahdar*, whose charge is about as large as that of an Assistant Engineer, and should embrace an area not exceeding 50,000 acres of annual irrigation, has the charge of all the water distribution. He should know what is going on in each village, where water is being well used, and where wasted. He is directly superior to the measuring ameens, and all the warrants for the collection of water-rate should bear his, as well as the Executive Engineer's signature.

The *Sub-Overseer* looks after the construction and maintenance of works, and take his orders from the Assistant Engineer. He should help too in seeing that tateels are enforced, and that water is not wasted.

The *Chokidar*, or canal policeman, has a patrol of 6 or 7 miles of rajbuha. This he should go over every day seeing that all is in order.

He should also inspect frequently the irrigation from every kolaba in his beat, and should be able to state positively what fields have received water. Being the most easily bribed he is the most corrupt of the canal establishment, and over him the superior officers have to keep a constant watch.

130. To the above may be added some practical hints extracted from a Memorandum by Major Brownlow, already quoted :—

General duties of Establishment.—An *Executive Engineer* should not tie himself down by assuming direct charge of works or administration of any particular portion of canal, but reserve himself for general supervision free to move wherever his presence may seem desirable. Having once distributed subordinate charges to the best of his ability, let him avoid as much as possible frequent changes in their extent or "per-

sonnel." These tend to unsettle the establishment and render it difficult to apply past experience or to trace and check irregularities.

They deprive a good man of much of his interest in his work and of his acquired local knowledge, while a bad one is seldom benefitted by change of air; "cœlum non animum mutant." The exceptions to this rule will be noted hereafter.

As a rule, all necessary orders should be given through the officer in charge of the work under inspection and not to his subordinates. When one of the latter is present and the former absent, the temptation to break this rule is often great, but except in urgent cases it is best adhered to, a contrary practice being decidedly subversive of discipline and good order. All orders especially to natives should be clearly conveyed in writing.

The Executive Engineer should constantly place himself in communication with Zemindars and villagers, unattended by the usual train of native officials. Then and not till then will they fearlessly state their grievances. He should transact all business in the vernacular as publicly as possible, and be perfectly accessible at certain fixed hours of every week day.

Anonymous petitions should never be listened to, but the repetition of open and acknowledged complaints, even though apparently disproved or grossly exaggerated, is a symptom not to be disregarded. They show that something is annoying the people, and though most natives will on slight foundation build up an astounding accusation, villagers will seldom go out of their way to trump up a *totally* groundless complaint.

131. *Assistant Engineers* should be held responsible for the maintenance in working order, at a reasonable cost, of the sub-divisions entrusted to them; for police arrangements and for proper distribution of water. To enable them to check their expenditure on current repairs and original works, the Divisional accountant should send them each month the schedule prepared by him, including all stock rates for materials. The Executive Engineer keeping them distinctly informed of total sums allotted to each account. They should be personally acquainted with the principal Zemindars irrigating from the portion of canal in their charge, and with the characters and capabilities of all their native subordinates. They should know the number and irrigating

capacity of outlets on each rajbuha entrusted to them. Should "tateels"* not have been previously established, they should arrange them when necessary and see that they are strictly adhered to. They should take every opportunity of verifying the accuracy of any measurements of irrigated land that may be going on in their vicinity. A young hand is apt to suppose that when once his rajbuhas are in good order he need not often inspect them, than which there can be no greater mistake. They may be in admirable order, but constant inspection will do more to keep them so, than many working parties. "The master's eye is worth a dozen hands."

132. On the Eastern Jumna canal, the *Native Deputy* is employed, as a general rule, in moving up and down the line, deciding the numerous petty disputes about water that are constantly arising, and where necessary, punishing infractions of canal regulations. He also checks the work of any measuring parties in his neighbourhood, inspects the Zillahdar's books, and makes himself generally useful. Thus employed, he has been always found an invaluable assistant, and I have never found it advisable to localise his duties by placing him in executive charge of a sub-division.

133. A good *Zillahdar* is a man whose importance cannot be overrated. He is the right hand of his superior in all matters connected with irrigation. He should know personally all the principal irrigators and owners of outlets, and be known by almost every resident in his Zillah (the latter being no bad test of his locomotion). He will know at any time where irrigation is going on, and pretty accurately to what extent, and consequently to what points water should be forced down his rajbuhas by "tateels." At the same time that he is watching the irrigation of the current *fusl* (harvest), he will be supervising measurements of irrigation. On the Eastern Jumna canal, each Zillahdar has an average of 200 villages, and 250 square miles of country over which to superintend irrigation, measure it up, and collect the revenue. His office books should be carefully kept up and frequently inspected and signed by the Executive and his Assistants.

134. *Sub-Overseers* are chiefly employed as purely executive officials on maintenance or construction of works, but can be made most valu-

* The closing of outlets at the head of any line of irrigation in order to force water down to the tail is meant by a "tateel" (*see* above).

able auxiliaries in superintending irrigation. A good man should have much influence in his beat, and be looked up to by the cultivators as second only to the Zillahdar. The average charge of a Sub-Overseer on the Eastern Jumna canal is about 10 miles of canal and 10 miles of rajbuha channels, with their dependent irrigation.

135. The influence of *Chokedars* for good or bad is so great that too much pains cannot be taken in selecting them, and in keeping their "morale" at the highest pitch attainable. I have always found promoted mates or tindals of working parties make the best chokedars, as they are generally hardy active fellows, and can, in case of emergency get repairs executed quickly and well; men of the "mirda" caste, from their aptness at estimating areas and acquaintance with land measurements, make good raw material, but great care is required in selecting them; from living in the large towns they are apt to be loose, idle fellows. The uniformity of pay and small prospect of promotion in this grade, led to a proposal being made to Government for increasing the pay of the most deserving chokedars on this canal as an inducement to exertion, which has since been sanctioned. It is perhaps advisable to change these men from one beat to another about once in two years, as it does not take a man long to get acquainted with his new charge, and they are apt, if left too long in one place, to make private arrangements for the distribution of water, decidedly detrimental to canal interests.

Their average charges should not exceed 5 or 6 miles of rajbuha or canal channel, and 10 to 13 square miles of country, over which to supervise irrigation, as otherwise a man cannot go out to distant points and return the same day to his chokie, having careful inspected the intermediate irrigation.

136. *Police and Revenue.*—Executive Engineers and their assistants have powers of an Assistant Magistrate for the protection of canal property, and these powers cannot be too cautiously wielded. A firm and vigilant officer will seldom have occasion to punish severely, as irregularities are easily checked at the outset. An Executive Engineer should be most cautious in accepting the assertions of his native subordinates that such and such villagers are irreclaimable scoundrels, and should occasionally call to mind a pithy native proverb, "The darkest place is under the lamp."

The most common offences are, grazing cattle on canal banks, making

ghâts across rajbuhas, breaches of "tateels," and stealing water from another person's water-course. In the first case, the chokedar can drive the cattle to the nearest pound, and if opposed (as is constantly the case) he must let them go as soon as they are off the bank, which is all he cares about. Where grazing is persisted in and damage done, it is patent and visible; the grass and perhaps some young trees are trampled down or slopes of earthwork are injured, and the people who are in the habit of grazing on the adjoining land should be held responsible for it.

Where ghâts are made by foot passengers across rajbuhas, there is no use in finding (at least I have never found it stop the practice); so, accept the situation, and place a couple of stout straight logs alongside of each other across the channel. People infinitely prefer going dry shod to wading through the water, and will consequently abandon the ghât for the bridge. I may here mention that no earth or brushwood should be allowed on a log bridge, as they are liable to fall into and choke up the rajbuha channel; the best plan is to purchase a suitable tree in the nearest village, halve and dress the trunk, placing the two pieces side by side. Where cattle are driven across the rajbuha, it is generally a sign of a village road having been left unprovided with a bridge, and the sooner one is built there the better.

137. In dry seasons, breaches of "tateel" are very common, and can only be put a stop to by constant and unexpected inspection of the lines on "tateels" are in force, and severe punishment of all offenders, commencing which with the canal establishment, who are pretty nearly sure to be in fault. Where a cultivator is accused of stealing the water from another man's water-course, a moment's inspection will verify the truth of the statement, as the breaches in the sides of the "kool" are apparent, as also the signs of irrigation. In such cases, settle the dispute by a village "punchayet."

Mill-rents should never be more than ten days in arrears, and fines should be realised immediately on infliction, otherwise they fail to answer their purpose as deterrent punishments and sink into a most objectionable source of revenue.

CHAPTER IX.

COST AND REVENUE.

138. The *Cost* of a permanent canal will evidently vary according to its size, the difficulties attending its construction, and the varying rates of labor and materials in different localities. It will be useful, however, to collate the experience derived from canals already constructed, or projected, so as to gather some idea of the *average* cost of such projects.

The total cost of the Ganges Canal up to end of 1868-69 (and including rajbuhas) was Rs. 2,34,35,716. Its estimated full discharge is 6,250 cubic feet per second. Its total length of main channel was 654 miles. This gives a cost of Rs. 3,750 per cubic foot of discharge, or Rs. 35,834 per lineal mile.

The Baree Doab canal will probably cost Rs. 1,35,00,000;* is calculated to discharge 3,000 cubic feet per second, and will be 469 miles long, giving an average of Rs. 4,500 per cubic foot, or Rs. 28,784 per lineal mile, exclusive of rajbuhas.

The Eastern Jumna canal has cost Rs. 19,13,529, up to end of 1868-69, being 130 miles long, and discharging 1,250 cubic feet per second, thus averaging Rs. 1,531 per cubic foot, or Rs. 14,719 per mile, excluding rajbuhas.

The Western Jumna canal has cost Rs. 24, 45,660† for a total length of 445 miles, and a full discharge of 2,500 cubic feet, being Rs. 978 per cubic foot, or Rs. 5,500 per lineal mile, excluding rajbuhas.

The Sutlej Canal, as originally designed by Major Crofton, was estimated at Rs. 1,10,19,000, (exclusive of permanent dam at the head,) for 530 miles, and a full discharge of 3,500 cubic feet, being Rs. 3,148 per cubic foot, or Rs. 20,790 per mile, without lockage; and exclusive of rajbuhas.

1,17,56,000 Rs. up to 1st April, 1869 † To 1st April, 1869.

The Soane Canals, according to Col. Dickens's design, were estimated at Rs. 1,35,72,000,* for a length of 826 miles, and a discharge of 3,124 cubic feet, being Rs. 4,344 per cubic foot, or Rs. 16,431 per mile; inclusive of rajbuhas.

The above data are too few† and discrepant to draw any very accurate conclusions from them, but excluding the Jumna canals, which were not entirely new projects, and assuming that the cost of rajbuhas will be Rs. 1,000 per mile, and that there will be four miles of rajbuhas to one of main canal channel, it would appear that a first class canal of irrigation when complete, with rajbuhas, will cost *about* Rs. 4,000 per cubic foot per second of maximum discharge, or *about* Rs. 30,000 per mile of length.

The above may be considered to include the whole cost of first construction, including establishment; while the establishment for maintenance, with the cost of annual repairs, will afterwards, of course, become an annual charge or drawback upon the revenue.

139. *Revenue.*—This is derived first and chiefly from *Water-rent*, which, as said above, may be charged on the amount of water distributed or the area of land irrigated. At present, we have seen, as it is universally on the latter, and the cultivator either takes it or not at each harvest, just as he fancies, according to the amount of rain that may happen to fall, or he makes a contract for the whole year or for a certain number of years. This hand-to-mouth system certainly seems absurd in the case of a great work which may have cost some millions, and which the Government is constrained to maintain in efficient working order at a great annual expense, and it is certainly desirable either that the contract system should be enforced everywhere, or at least that those not taking water until the last minute should pay at a higher rate in proportion to the delay. By the new Canal Act now before the Indian Legislature, lands capable of irrigation from a new canal will practically be compelled to pay for the water whether they use it or not, and thus there will be every chance of such works returning a fair percentage on their first cost.

* Excluding the cost of the permanent dam at the head, which amounts to Rs. 18,00,000 more. The length of this canal is much greater in proportion to the discharge than that of the others.

† I have not had the opportunity of perusing the projects for the Sirhind, the Lower Ganges, and the Sarda Canals, which have recently been drawn out, but hope to be able to do so in time for the next edition.

140. The following are the rates for water now in use on the Ganges and East and West Jumna Canals:—

		Flush.			Lift.		
		RS.	A.	P.	RS.	A.	P.
1st Class.	For sugar, per annum, per acre, ...	5	0	0	3	5	4
2nd Class.	For fruit, nursery and vegetable gardens, singharas, cultivated grasses, lucerne, guinea grasses, &c., ajwain and similar herbs, rice, per crop, ..	3	0	0	2	0	0
3rd Class.	For indigo, cotton, tobacco, wheat, oats,	2	4	0	1	8	0
4th Class.	For Indian corn, safflower, cheena, barley, gochnee, oil, seeds, jowar, pulses of all kinds, per crop, ..	1	10	8	1	0	0

A proposal is now before Government to raise rice to a 1st class crop, on account of the quantity of water it requires and the difficulty of giving it; as also somewhat to check the very rapid extension of a cultivation, universally accompanied by malaria and fever.

141. Villages taking water from the canal for irrigation are exempt from all charges for watering their cattle and for water required for domestic purposes. Other villages pay, for watering cattle, 6 Rs. per 100 per annum; watering sheep or goats, 2 Rs. per 100 per annum. For filling tanks (not irrigating), the water is paid for at 1 rupee per 6,000 cubic feet in bulk.

Transit dues are fixed from time to time for boats or rafts plying on the canal.

Other sources of revenue are from *Corn mills*, which are built by Government, and rented annually to the highest bidder.

Canal produce, such as grass, &c., also sold annually. *Fines* for breaches of canal regulations, such as stealing water, trespass, &c.

142. On the Baree Doab Canal, all crops are charged for at the same rate, viz., 2-6-8 per acre for *flow*, and 1-3-4 for *lift*, irrigation.

On the Soane canals, the expected water-rent was reckoned at Rs. 1-9-0 per beegah, per annum for the two crops, or Rs. 1-12-2 (equivalent to Rs. 2-8-10 per acre) if the rajbuhas were made at the Government cost, as was proposed.

143. But besides the direct return from water-rent, there is an indirect return due to the canal, arising from the increased value of the land, and therefore the increased rent or land-tax that it can afford to pay to Government, the difference in produce between well and canal

irrigated* land being considerable, while the difference in cost of irrigation under the most favorable circumstances for each, is reckoned as 3 to 1 in favor of the latter. This indirect canal revenue may, and does often, amount to considerably more than the annual value of the water-rent, and though it does not appear in the canal returns, the work should always have credit for it. In the N. W. Provinces it is estimated at Rs. 1-8 per acre, per annum, on the whole area irrigated. Much discussion has however risen on this point, which is complicated by the land-tax being assessed for 30 years, so that no increase of revenue can be obtained until the expiration of the settlement.

144. Allusion has already been made in a former Chapter to the effective work done by every cubic foot of water in a canal, generally called the irrigating duty per cubic foot. It is evident that by dividing the total annual water-rent received during the year, by the average discharge per second throughout the year, the annual value of each cubic foot of water can be determined.

From the latest returns available, the following table has been compiled :—

Name of Canal.	Average discharge per second throughout the year at the head.	Area irrigated	Area irrigated per cubic foot of supply	Total water-rent	Value of supply per cubic foot.	Water-rate per acre irrigated.	Length of rajbuha open.	Area irrigated per mile of rajbuha.	Water-rate per mile of rajbuha
1868-9.	c. f.	acres.	acres.	Rs.	Rs.	Rs.	miles	acres.	Rs.
Ganges canal, ...	4,646	1,078,899	232	22,65,320	488	2·11	3,112	357	728
Eastern Jumna canal,	962	2,74,101	306	5,99,580	623	2·18	596	460	1,006
1868-9.									
Baree Doab canal, ...	1,850	2,99,835	162	7,06,324	382	2·35	688	436	1,027
1868-9.									
Western Jumna canal,	2,278	4,72,063	207	11,66,919	512	2·47			

The irrigation in the Ganges and Baree Doab canals is not yet fully developed, though steadily and rapidly increasing on both. The Eastern Jumna canal returns, however, may be safely and fairly taken as a guide in estimating others.

* Settlement Officers deny this, and assess well irrigation in some Zillahs as high as canal irrigation. Any how, *unirrigated* land is never assessed at more than one-half as much as irrigated land.

145. The rate of expenditure on well managed canals in good working order may be taken at Rs. 120 per cubic foot, with an extra Rs. 50 for rajbuha repairs, if they are done by Government. The difference *between the income and expenditure, is* the clear profit per cubic foot *of discharge per annum, whence the percentage of return on the original cost of the work can be determined.*

Say for instance that the average prime cost of a cubic foot of water per second of discharge is, ...			Rs. 4,000
Average annual value of a cubic foot, say	Rs. 500		
Deduct average annual expenditure on a cubic foot, ...	„ 120	„	380

showing an annual profit of about $9\frac{1}{2}$ per cent.

This calculation is for water-rent only, and takes no account of the enhanced value of land; assuming this enhancement, as said above, at Rs. 1-8 per acre annually, and that each cubic foot irrigates 220 acres, then the net returns would be swelled from Rs. 380 to 710, and the return on the capital would be $17\frac{1}{2}$ per cent.

146. It is evident, however, that the data for the above calculations are exceedingly variable, and canal statistics are too imperfect for them to be considered as anything more than rough guides—as such, however, they are valuable. The saving in remissions of revenue which are often forced upon Government during seasons of drought, in districts where artificial irrigation does not exist, and the general prosperity of the people, are also items, which although they cannot be exactly reckoned by figures, are of not the less importance on that account, and must be set down as very tangible benefits derived from canals. The value of the crops irrigated by the Ganges canal in one year was estimated at $1\frac{1}{2}$ millions sterling, of which the sugar, cotton, and indigo, valued at upwards of £600,000, were almost entirely due to its influence; and wheat, valued at nearly half a million, was largely indebted to it.

147. When the Government first undertook the construction of these Irrigation Canals, it was done rather to insure the people from the horrors of famine and to secure the punctual payment of the land tax, the largest item in the revenue of the country,—than with the idea of securing any direct returns from them. It is now seen, however, that, though not likely to yield the extravagant returns which were at one time looked for by sanguine speculators, they ought to yield a fair

interest on their cost if made on proper principles. But these principles have been the subject of much discussion, and are still far from settled. The question generally is,—Having a limited quantity of water, how ought it to be expended? Shall it be conveyed to the lands which most require it, or to those where it will yield the largest profit? Where *land is already irrigated by wells and* where there is a population ready to use whatever will greatly increase the value of their land, canal water would evidently yield a larger return than if it were conveyed probably a longer distance to a sterile soil with a scanty population where well irrigation is impossible. But Government cannot already look upon such questions simply with the eye of a speculator. In the latter case, the population of a district might be reclaimed from lawlessness and preserved from famine by the introduction of a canal, and this might be a sufficient inducement to undertake the cost even with the certainty of a loss.

148. One other point remains to be noticed in connection with the benefits from Canal Irrigation,—the raising of the surface water in wells owing to the percolation from the canal, whereby the labor and cost of well Irrigation is of course very much lessened; moreover, in many of the desert districts, where brackish water has alone been found before the construction of the canals, the effect of the latter has been to sweeten the well-water, and make it palatable for drinking.

149. Against these benefits has sometimes to be set the formation of *jheels* or swamps in low ground, which, however, may generally be reclaimed by proper drainage. Another evil is the presence of the saline efflorescence (known locally as *Reh*, in the N. W. P.), on some kinds of soil when irrigated* which greatly injures its productive value. On the Western Jumna Canal, this evil has been the subject of serious consideration, and I believe it is partially developed on the Baree Doab Canal. The salt appears to be in the ground at a certain depth, and to be developed only after being flooded with water—and hitherto no effectual remedy has been devised for it.

Still these are very small and partial sets-off against the immense benefits due to Irrigating Canals.

* This evil however is not the result of canal water only. Well irrigation is often more conductive to its production than canal irrigation.

The minor items of Revenue from Irrigation Canals, and which have been named above, need not further be commented upon here.

150. From the report of the Chief Engineer of Irrigation, N. W. P., it appears that the net profit for the year 1867-68, upon the original cost of the Eastern Jumna Canal, was 19 per cent., or 39 per cent. if the estimated enhancement of land revenue due to the canal be included. And for 1868-69 for the Western Jumna Canal, the profit is 37½ per cent., or taking into account the increased land-rent due to its influence to 53½ per cent. on the original outlay. The above includes the *direct* returns.

As these are the only two canals of any size on which the Irrigation has been as yet fully developed, (indeed the Western Jumna Canal is still far from perfect,) the above returns are of interest and value—and seem to prove that a good remuneration from such works will in the end accrue to their proprietors, if designed and carried out on proper principles. On the other hand, no Engineering Works require so much anxious forethought and scientific design as Canals of Irrigation, as none require more skill in construction, as regards both the workmanship and materials employed.

CHAPTER X.

MADRAS CANALS.

151. The Madras System of Canal Irrigation, like that of the North Western Provinces, is simply a development of the old native method, improved on scientific principles and carried out in a more permanent manner.

A general outline of the native system may be given in a few words. Channels of supply, proportioned in dimensions to the area of the tract dependent upon them for irrigation, were cut from the river bank, and supplied sometimes with head sluices of masonry, but very often wanting in these necessary works. The levels of the heads were so arranged as to command a full supply in moderate floods, and the water was led to the fields by infinite numbers of smaller channels of distribution. When the level of the river surface was too low for the supply of the channels, the construction of a temporary earthen dam (corumboo), or a permanent masonry dam (anicut) was had recourse to, and the water was thus raised to the requisite height.

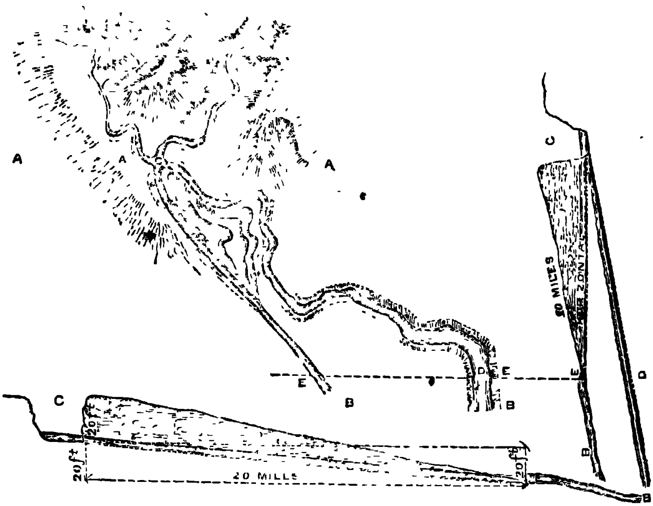
Our improvements on this system have consisted in establishing permanent Dams to replace the temporary ones, and in a better alignment of the irrigating channels, which are in fact much the same as those described in the first Chapter as Inundation Canals, with this important difference, however, that by the construction of the Anicut or Weir at the head, the regularity of their supply is improved.

The generaly fall of the Deltas, on which the largest works have been constructed, ranges from 1 to 3 feet per mile, from the head down to the sea. The difficulties, therefore, that have to be encountered in the Upper Provinces from an excessive fall in the upper part of a Doab, and from the country being cut up by formidable hill torrents, are not met with in these Delta works; and they have the still greater advantage of being continually progressive, both as to cost and revenue; in

other words, the returns from them are quicker, and perhaps more certain.

But besides the great works on the Deltas, irrigation is largely carried on in the plains higher up, by numerous supplying channels cut from minor streams, across which anicuts are thrown, and leading to the fields themselves or to tanks, in which the water is stored up for future use.

152.* A plain which it is desired to irrigate can hardly be so situated, but that the bed of a neighbouring river is at some part or other of



Note.—In the plan, the same letters refer to spots that are on the same level.

its course relatively higher in level. Supposing a surface AB to slope from A to B at the rate of 2 feet in a mile, and to be traversed by a river CD, the bed of which falls at the same rate, but is throughout 20 feet below its banks, it is evident that the part of the slope which is 10 miles from A towards B will be on the same level as C, and that were a channel CE excavated, with a horizontal bed, water from the river above C would flow along it until it reached E, whence it might be conducted to irrigate the lower portions of the slope EB.

In like manner, if the bed of the channel were made to fall one foot per mile, it would at 10 miles be only 10 feet below the country; and

* The next paragraphs are from a report by the late Captain Best of Madras Engineers, published in the Madras Professional Papers several years ago.

at 20 miles, having gained a foot per mile, it would emerge on its surface.

The case is more unfavorable, but still similar, though the country would also slope, as it most frequently does, towards the river, as well as towards the sea. In this case, the water for the lands farthest from the river must be brought from a part of the bed nearer to its sources, and the excavations must be deeper; or, as will often happen, the expense bearing too high a ratio to the attainable advantage, the irrigation must be restricted to those lands which lie nearest to the course of the river, and at the lowest levels.

Channels of irrigation have been taken off rivers, such as the Palaur in Arcot, the fall of the bed of which is at the rate of nearly 10 feet in a mile, and its ill defined banks 6 to 8 feet high; as well as from such as the Kistna, which runs with a fall of less than 1 foot per mile, and between steep banks of 35 feet.

It is the relative fall of the river and of the country on its banks, which determines the least length which the channel can have, in order that its bed should emerge above the surface, and its water be brought to use; but when the freshes are of short duration, and channels are led to tanks, it is evidently desirable in order that they should deliver water rapidly, that they should be wide, and the velocity of water in them considerable, although to afford slope to their beds, their length should be extended, and the expense of excavation increased. Six or eight yards may be considered the greatest depth to which irrigating channels have yet been excavated in this Presidency, but the general average is not more than 2 or 3 yards.

153. Great portions of some channels have been formed by throwing up one bank only on the lower side of a slope; and the heads of some river channels, by separating part of the bed of the main stream by means of an artificial bank, protected by river grasses, &c. In some cases, these artificial banks are carried for very considerable distances up the rivers, or obliquely across their sandy beds. Such banks termed *Corumboo*, are generally over-topped and carried away by all freshes of more than 1½ yards depth of water. They are temporary expedients or substitutes for permanent dams or anicuts, to turn the early and low freshes of rivers into irrigating or tank channels, and being liable to be partially, and sometimes entirely destroyed by every full fresh, require

to be repeatedly repaired, and occasionally reconstructed during every season. They are usually constructed and kept in repair by the proprietors of the lands which they irrigate, without any cost to Government.

154. The word "*Anicut*" is Tamil, and means generally dam or weir. Engineers have generally restricted the use of the term to a dam across a stream, and that of the word "Calingulah" to a work of similar form in the bank, either of a supplying stream or of a tank.

The chief object of Anicuts is to raise the water of the streams they are built across, in order that a portion of it should be diverted into channels, leading, as the case may be, directly to the fields or to tanks, in which the water is stored up to be used as required, and they have the further effect, of reducing the depth of excavation near the head of the channel. Some anicuts are like calingulahs, furnished with dam-stones to sustain temporary banks of mud, &c., and to raise the water in the river beds during the dry season and the early and low freshes; such temporary embankments being washed away by the freshes. Others are provided with sluices, or have low parts or gaps left in them, seldom exceeding 5 feet each; within which limit, it is not difficult to provide means of closing, such as shutters, &c. By these, the sand is more or less prevented from accumulating to the height of the crown of the dam; and parts of the beds of the rivers, generally inconsiderable however, are thus formed into pools extending towards their sources.

These are in no instance looked upon in the light of tanks. They may, for a trifling period at the very end of the dry season, answer the same purpose, but the irrigation depends in all cases either upon the continual flow of a small quantity of water during the early part of the hot season, or upon tanks generally far away from the river, and which are supplied by channels during the freshes.

155. Almost all the rivers in the Carnatic, are little more than beds of dry sand during the hot season, and very little water can then be procured from them for the purposes of irrigation. During the monsoons, they are more or less full, and it is then only, or at least chiefly, that a portion of their waters is directed by means of anicuts and channels into the adjoining country, to moisten and fertilize the rice and garden lands. During the periodical rains, there is generally too much water, and in the hot months none, and the object of all the expedients and works of irrigation is to rectify these evils, by collecting and retaining in tanks or reservoirs

portions of the surplus water of the monsoon, for the irrigation of the country during the dry season.

When the slope of the country is gradual, it is evident that a dam across a river may, by raising the water in its bed, very much diminish the length of an irrigating channel to be led off it, and it might appear that anicuts would on this account be found general in the *lower* parts, of the courses of rivers, where the fall is gradual. But this is not the case, because the lower parts of rivers are generally wider, their beds sandy and unfavorable to such buildings, and their banks low. The obstruction of the bed in such localities would raise the surface of the water in freshes, and render necessary the formation of banks, to prevent the inundation of the country through which the river passes: for, however advantageous such inundations are in the Deltas of the Ganges and Godavery, they are most carefully guarded against on the banks of the Cauvery and Tambrapoorny, where the crops are raised, not by *inundation*, but by a very artificial, and (as far as the science of agriculture is concerned) a very perfect system of *irrigation.*

156. Anicuts are most generally useful nearer to the sources of streams where they traverse rocky country. In such situations, rocky foundations can generally be obtained, and the work built securely, while, although the fall of country is great, and channels do not need to be very long, yet without anicuts, the difficulty arising from the nature of soil, in such parts generally stony, and which it would be necessary to excavate to a great depth, would be very often absolutely insuperable.

A rocky bed, though a great advantage, and always to be preferred in selecting a site for an anicut, as contributing to reduce the cost and increase the stability of the work, is not however an indispensable requisite. Several anicuts have recently been built with perfect success, and at a moderate expense across rivers, the beds of which consist entirely of pure sand to a depth far beyond the foundations of these works. On such occasions, the chief point to be studied is the formation of a strong and substantial apron beneath the anicut, to break the over-fall of the water, and prevent the foundations being undermined.

Generally, in the wide and flat beds of rivers near their mouth, the scanty supply of water during the dry season is collected and turned into channels by means of the temporary embankments of grass, baskets, sticks and sand, which have already been mentioned by the name corum-

boo; but there are two modern Anicuts in such situations, whose success has since led to the projection of others in similar situations.

157. These are the upper and lower Anicuts across the Coleroon, built at the suggestion, and under the superintendence of, Captain (now Major-General) Sir Arthur Cotton, of the Madras Engineers. Both these works have superseded and rendered unnecessary the construction of extensive corumboos; while, unlike, corumboos, they resist the action of freshes, and assist the irrigation in all states of the river. The upper anicut is built where the Agunda (or whole) Cauvery divides into two branches: the Coleroon, which seeks the sea by a straight course, falling at the rate of from 2 to 3 feet per mile; the smaller but more useful branch (which retains the name of Cauvery) flowing on a more elevated bed, and, after having in the short distance of 40 miles, gained no less than 15 feet on the level of the bed of the main branch, dividing and sub-dividing until its water is spread over the greater part of the Tanjore District. For many years previous to 1836, the Tanjore cultivation had pressed so closely upon the supply of water afforded by the Cauvery, that in seasons falling at all below the average, extensive tracts of valuable land either remained uncultivated, or were subject to the still greater evil of being cultivated in vain. The defect was chiefly attributed to the accumulation of sand in the upper part of the stream near its separation from the Coleroon, and to remove which various expedients were devised, and adopted with partial, but only temporary success.

At this conjuncture, viz, in 1834, Captain Cotton, then Civil Engineer of the Division, devised the anicut which is built cross the Coleroon, about 100 yards below the separation of the two rivers, and by raising the bed of the Coleroon about 6 feet, has, without diminishing except in a trifling degree, the capacity of its section for the passage of high freshes, rendered available for the supply of the Cauvery and of Tanjore, all the water which, even in the driest season and when most wanted for irrigation, used to pass waste to the sea. The lower anicut was built in the same year, about 70 miles down the same river, and serves to turn the water, that accumulates in the intervening part of the river bed, from the drainage of cultivation and the springs that ooze from the sand, into the country on both sides, irrigating extensive and fertile tracts of land in the Tanjore and South Arcot districts, between the anicut and the sea.

158. These works had a very beneficial effect, but it cannot be said that the irrigation arrangements under the Cauvery are yet in a satisfactory condition. Regulating works are required at the heads of the numerous branches which at present are not supplied in proportion to the areas of land irrigated, and measures have also to be devised for diverting from the Delta the injuriously high floods, which are now liable to pour over it. It is understood that works to answer both purposes are under contemplation, and that several of the minor regulators, which, however, are still very extensive works, have already been constructed.

159. Anicuts, as usually constructed, are walls of masonry erected on a solid foundation and carried right across the whole breadth of the river. The material used is either stone throughout, or brick-work covered with cut stone, the foundations usually resting on shallow wells sunk in the sandy bed of the river (unless the site happily offers a rocky foundation), and the superstructure made partly of dry stone and partly of stone set in mortar. The sill of the anicut over which the flood-water pours, is of cut stone set in the best cement. The face of the work may be perpendicular or nearly so; the rear will be made into a long slope, which gives great strength to the work and protects the rear flooring from being injured by the water falling vertically on it. When, however, it is necessary to have a vertical fall on the down-stream side in any portion of the weir, either on account of sluices being fixed there or for any other reason, the flooring is carefully protected by large slabs of cut-stone laid on an unyielding foundation with fine mortar joints. In any case, the bed of the river is protected for a considerable distance down-stream from the action of the water at the tail, by a flooring of dry stone of the largest size procurable, and carefully packed by hand. The water will often work holes even in this, which have to be filled up with more stone, and this will often continue for several seasons before the work is safe.

160. It will thus appear that such a weir requires the expenditure of a very large quantity of material, and that without the presence of an abundance of stone on the spot, its construction as above would not be feasible, or at least would be enormously expensive. Had such a work to be made of brick, the foundations would have to be much deeper, the body of the work would be of the best pucka masonry, and

similar arrangements for the flooring and sides on the down-stream side as have already been described as necessary in the case of canal falls.

161. The shallow foundations of these works are a peculiar feature in Madras Engineering, and a similar practice in bridge building has been already commented on in para. 131. In the case of anicuts, the arrangement is evidently only practicable from the long talus or slope of dry stone given invariably on the down-stream side of the work, which is free to fall in and fill up holes scoured out by the under-current, and is replaced continually by fresh renewals. A similar arrangement to this is the cribwork of boulders provided so carefully on all the Ganges Canal bridges. In the dry season, however, deeper foundations would probably be preferable in order to prevent so much percolation below the weir, and the consequent loss of so much water. But in Madras, unlike Upper India, the crops raised at this season are far less valuable than those grown in the rains, and this difference necessarily produces a difference in the plans of the Engineers. There is also good reason for believing that the coarse sand of the beds of rivers in Southern India is much less disturbed by the action of running water, than the fine sandy beds of Upper Indian rivers.

162. The weir now building at Okla, near Delhi, the head of the new Agra canal has even a bolder design, being actually constructed without any foundation at all. It is of cut stone laid in cement and well bonded, the lower course being simply laid on the sandy bed of the river. It has at present a thickness of 4 feet and a height of 5 feet, with a talus of loose stone both in front and rear, and has stood the effects of the heavy floods of 1870 uninjured. It is now to be raised to 9 feet, the talus in front being laid at a slope of 4 to 1, and in the rear of 20 to 1.

163. As the water when it arrives at the head of these Deltas is much charged with silt, the effect of this upon the anicut has to be carefully considered. In the earlier works, a number of small sluices of about 2 feet in width were provided, through which the silt should be scoured, but their size made them quite ineffective, and Colonel Baird Smith has given it as his opinion, that so long as a we[illegible]preferred to an open dam, the elevation of the bed above, by th[illegible]osit of silt, even up to the level of the crown of the weir, must be[illegible]rded as a probable result and provided for accordingly.

164. The following description of the Kistna anicut is extracted from the author already quoted :—

Nature has indicated by unmistakeable signs, that the true position for the Kistna dam is at Bezwarah, about 60 miles from the junction of the river with the sea. Here there are two low hills, the last outlying spurs of the high lands to the north. Between them the river flows in a channel reduced to a manageable breadth of 1,300 yards, but with a depth of water so variable that no single statement would give a correct view of it—rising as it does, during the monsoons, to between 30 and 40 feet, and sinking during the dry season to, perhaps 5 or 6. The hills in the neighbourhood of Bezwarah furnish an unlimited supply of stone for building or protective purposes ; lime is readily procurable, as are all the other materials required for the work. The position is exactly at the apex of the Delta, and the height is sufficient for purposes of irrigation. Its construction has presented some peculiar difficulties from the fact that the river is concentrated into a single undivided channel between the Bezwarah and Seetunagram Hills. It has, therefore, been necessary to work constantly in water, and the design of the dam has special reference to this necessity. It consists—1st, Of a broad basis of the heaviest stone that could be procured, simply thrown into the river and allowed as it accumulated to assume its own natural slopes. The exact length of this mass of stone is 3,750 feet ; its breadth 305 feet ; its height in front, 21 feet above the deep bed, and 14 feet above the summer level of the water. It is faced along its entire length by a casing of stone masonry* 75 feet in breadth, of which the front curtain wall is 9 feet thick at bottom, 4 feet at top, and 14 feet high, resting on a double row of foundation wells which fill up the space between the deep bed and summer line levels, being therefore 7 feet in depth. The sill or wasteboard is 20 feet in breadth, and 5 feet in thickness, 4 feet being of masonry and the upper foot of cut stone strongly bound throughout with iron clamps. The tail of the masonry casing is a flat semi-counter arch with a half chord 50 feet in length, and a versed sine 10 feet in height, and this portion is terminated by a rear curtain wall running along the entire length of the dam, 8 feet in depth and 3 feet in thickness, embedded in the loose stone-work of the main body of the dam. At a distance of 50 feet from the rear wall of the casing, a second line of masonry, somewhat irregular in dimensions, but averaging about 6 feet in thickness and 5 feet in depth, crosses the work from right to left, acting as a retaining bond to the rough stone-work at the part most exposed to danger from the action of the current in floods. From this wall to the deep bed of the river, the slope is worked out by the aid of rough stone-work extended over a distance of 180 feet.

At the right and left extremities of the dam, under-sluices are provided for the purpose of scouring out the silt in front of them, and thus keeping an open channel at the heads of the irrigation lines. No under-sluices have been made in the body of the dam, and the filling up of the river-bed in front to the level of the crest of the work has apparently been accepted in this case as an inevitable result. The sluices above-mentioned are two in number, and similar in all respects. They are situated at the extreme limits of the dam, one at each flank, and consist of massive masonry

* This was not carried out, rough stone packing was substituted for the cut stone on the original drawing.—*See* Professional Papers, Madras Engineers.

structures founded on wells, in the usual native fashion; each has 15 vents of 6 feet in breadth each, fitted with planks and machinery for opening and closing; the level of the flooring is 3 feet below that of the heads of the irrigation channels, so that when the vents are open, there will be a very efficient scour in front of them, and a deep clear channel maintained thereby through the light sandy deposits in front of the dam. The head-sluice of irrigation on the right of the river has fifteen openings, each 6 feet in width, with a clear height for the passage of water (as measured on the plans) of 11½ feet, exclusive of the archway. It may be assumed, however, that an average depth of 10 feet in the channel would represent the full supply of water during the season of irrigation, under the existing arrangements; with the dimensions specified, and a slope of about 12 inches per mile, the discharge would be equal to nearly 3,500 cubic feet per second, sufficient for the irrigation of 140,000 acres of rice. On the left bank, similar arrangements are made by a sluice of the same waterway as above.

165. Col. Baird Smith thus sums up the points of professional interest which he considers established by the success of the Cauvery works, above described:—

1st. That the water of large rivers may be distributed between their branches in proportions sufficiently exact for practical purposes, by the use of dams at the points of separation, having their crowns at such heights as experience in each case may prove to be necessary.

2nd. That the influence of such dams, judiciously established on the beds of the rivers, in regulating the currents, in equalizing the distribution of deposits, and in maintaining the permanency of the sections of the beds, may be very beneficial.

3rd. That in rivers with beds of pure sand, and having slopes of 3½ feet per mile, such dams may be constructed and maintained at a moderate expense.

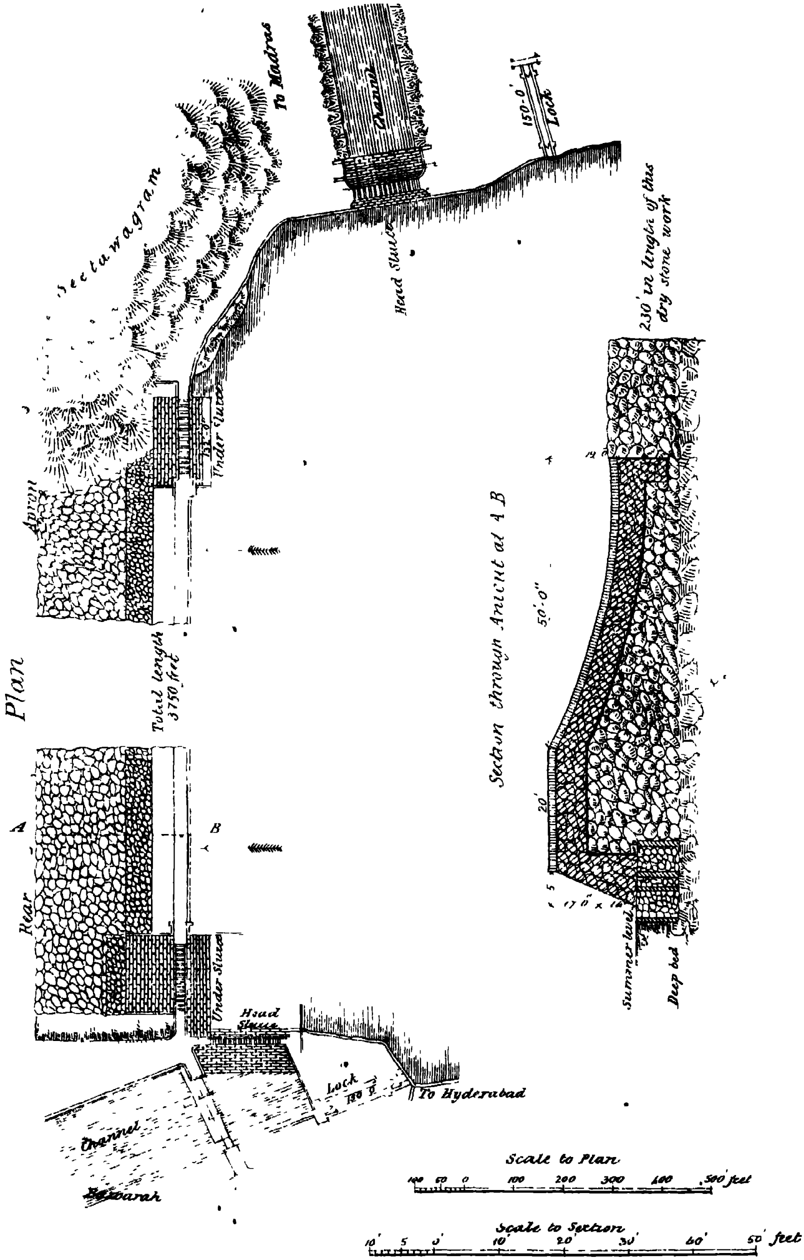
4th. That the elevation of the beds of the rivers above the dams to the full height of the crowns of these works, is an inevitable consequence of their construction, and that no arrangement of under-sluices has, as yet, been effective to prevent this result.

5th. But, that where effective escapes are provided in the banks of irrigating rivers (like the Cauvery), the entire volumes of which are absorbed in irrigation, it is possible to prevent any injurious elevation of the bed by sand deposits.

6th. That in pure sand acted on by the current due to a fall in the river bed of 3½ feet per mile, and exposed further to the action of floods from 12 to 15 feet deep, well foundations, in front and rear, of 6 feet in depth, have been proved by experience to be safe.

7th. That with a vertical fall in rear of the dam from 5 to 7 feet in

KISTNAH ANICUT.



height, a thickness of 2 feet of brick masonry, and 1 foot of cut stone, with a breadth of from 21 to 24 feet for the apron, have proved sufficient to insure stability, the only further protection required being a mass of rough loose stones about 9 feet in width and 4 in depth. As a rough general rule, it would seem that the masonry apron should have a thickness equal to half, and a breadth between three and four times the vertical height of the bar forming the obstructive part of the dam. The loose stone apron should at first have a breadth equal to one and a half times, and a depth equal to two-thirds the height of the dam. The action at the tail of the work leading to constant additions to the loose stone, soon deranges these proportions, and they are given only as guides in the first instance.

8th. That the main security of the dam depends upon the efficient construction and careful maintenance of the apron.

9th. That in freshes, the dam speedily receives the protecting effect of a backwater on the apron; the surface level of the down-stream side being level with the crown of the work when the floods rise to 8 feet above ordinary low water, while beyond that depth, the fall over the dam gradually diminishes, till in 16 feet floods it has wholly disappeared, and scarcely even a ripple on the surface indicates the existence of the mass of masonry below.

10th. That looking to the cost of the works executed between 1836 and 1853, and the increased area of irrigation due to them, the capital sunk amounts only to Rs. 6-8-0, or about 13*s.* per acre.

11th. That after deducting every expense which the irrigation works of the Cauvery have entailed on Government, the net returns may fairly be estimated at not less that $23\frac{1}{3}$ per cent. on the invested capital.

166. The works still in progress on the Godavery are similar in principle (though considerably larger) to those already described. The following is a description of the Great Anicut at the head, upon which the whole system depends.

The Godavery anicut consists of a masonry dam in separate portions, the united length of which is $11,866\frac{1}{2}$ feet, or $3,955\frac{1}{2}$ yards, being very nearly $2\frac{1}{4}$ miles of river channel blocked up by a solid, substantial, well-protected mass of stone in lime cement, or without it, according to position, having a total breadth of base equal to very nearly 130 feet, and height of crest or sill equal to 12 feet.* The three main objects

* The separate masonry portions are connected by earthen embankments, between six or seven thousand feet in length, and protected at the junctions by fully 2,500 feet in all, of masonry revetments.

of the dam—clearance, irrigation and transit—are provided for by three separate sets of works, one on each mainland flank, and one at the head of the central tract. The under-sluices discharge the necessary functions of the first object, the head-sluices those for the second, and the *navigable canal and locks* those for the third. Along the entire length of the masonry dam is carried a line of cast-iron uprights about 6 inches square, and 8 or 10 feet apart, having grooves on each sides for the reception of 2¼ feet of planking, whereby the water can be retained to that height above the sill during the dry season, and a larger volume be thus thrown into the irrigation heads.

The irrigating channels are, or will be, carried along the subsidiary ridges by which the Delta is intersected, and the water is at a sufficiently high level for surface irrigation everywhere.

167. Instead of the small sluices provided, as in the Kistna, and other anicuts, a larger kind of sluice on the French pattern has lately been successfully employed on the Mahanuddy anicut in Orissa.

The centre sluices are divided into ten bays of 50 feet each by piers of masonry. Each bay is closed by a double row of timber shutters, which are fastened by wrought-iron bolts and hinges to a heavy beam of timber embedded in the masonry floor of the sluices. There are seven upper shutters and seven lower or rear shutters. The latter are 9 feet in height above the floor, and the former 7½ feet.

During floods, therefore, the upper row of shutters, which fall forward is fastened down by clutch gearing in an almost horizontal position, while the rear set of shutters, which fall backward, is kept during flood in a horizontal position by the water rushing over.

During the summer season, these rear shutters, have to do the duty of damming up the water, and for this purpose they are provided with strong wrought-iron stays or struts attached to them behind, or on their lower side. As it would be almost impossible, however, to lift these back shutters with a depth of 5¾ feet of water tearing over them, the upper shutters are so constructed as to render this a matter of comparative ease. As the upper shutters point up-stream, the natural tendency of the powerful current passing over, is to lift them up. By simply unclutching them, therefore, they immediately rise and dam up the water, being retained in position by two sets of chains, which take the strain off the hinges. The water being thus dammed up, the back shutters are easily lifted, and permit in their turn of the upper shutters being lowered forward into their horizontal position.

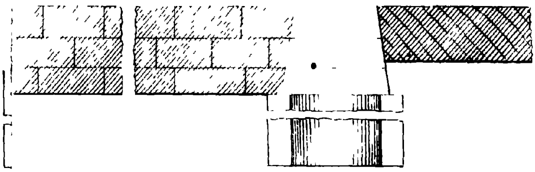
The catch
the shut
derneath
and sup
then be t

The strut E
Groove G w

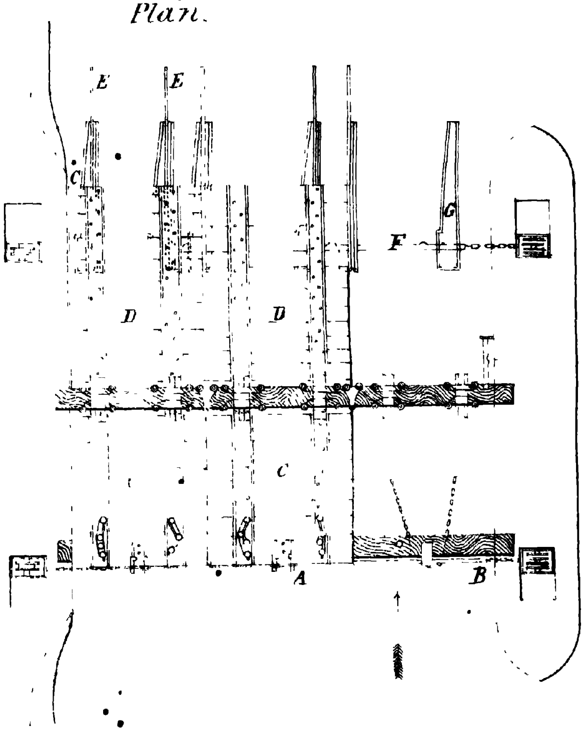
SLUICES OF THE MAHANUDDY ANICUT.

Details of movable shutters
for centre sluice.

Scale, 8 feet = 1 inch



Plan.



The Superintending Engineer, Mr. Walker, in reporting on them considers it is established—

1st.—That with the shutters constructed on the French pattern, and with a head or pressure of between 5 and 6 feet, 500 lineal feet of shutters can be easily lowered in one hour.

2nd.—That, under the same condition, an equal length of opening can be closed in 25 minutes. In closing, the shutters may be said to be self-acting.

3rd.—That when the back stays are released, the falling shutters are received upon a cushion of water in time to prevent any undue concussion.

4th.—That the action of the water in lifting the upper shutters brings no excessive jerk on the chains; but that it is advisable that chains have an adjusting screw fitted on, so as to make the strain perfectly uniform. The shutters were brought home in a current of 10 feet per second.

5th.—That three men can knock away the back stays with a pressure of between 5 and 6 feet with ease and security.

6th.—That twelve men are necessary to lift each of the back shutters into position.*

168. The following is a Memorandum by H. C. Levinge, Esq., Chief Engineer, East India Irrigation and Canal Company, on the projected Anicut and Canal from the Soane in Behar.

Anicut.—The position determined upon for the anicut is 2,000 feet above the cause-way at Dehree. The level of bed of the river at the place selected may be taken at 301, and the anicut being 8 feet high, the level of its crest will be 309·00. The length between the abutments is 12·550 feet, or 2·35 miles; it will be provided with three sets of under-sluices as shown on the drawings, each 500 feet in length: one set on either flank, and one set in the centre of the river. The drawings show the latter only provided with folding back-shutters in bays of 50 feet, but should the experiment with these shutters now being tried at Cuttack, in the centre sluices† of the Mahanuddy Anicut prove successful, I propose substituting them for the ordinary ones on both sides. There can be no question as to their much greater efficiency, the numerous piers in the ordinary sluices proving a great obstruction to the flow of the water.

Discharge of Soane.—From a careful cross section of the river taken at Dehree, and from the reliable flood-level of September 1864 (the highest on record) cut on the cause-way at Baroon, the discharge of the river has been ascertained to be 1,026,172 cubic feet per second; the mean depth at highest flood being 11·64 feet, and the breadth between the banks 12,400 feet.

Calculation of discharge over weir.—The depth of water over the weir in times of highest flood will be 6½ feet. From the formula, $D = 3{\cdot}5 \times l d \sqrt{d + {\cdot}035 w^2} + 8{\cdot}02 \times l d_2 \sqrt{d + {\cdot}0153 w^2}$, the afflux will be found to be 1 foot 3 inches.

Head-sluice.—The head-sluices on either side are designed to discharge 4,500 cubic feet per second, with a head of 4 inches, and depth of water 9 feet; they consist of 24 vents of 6 feet wide each; the shutters will be raised by a traversing hoist, the design for which has not been prepared as yet.

* *See* No. CCLXII. of Professional Papers [First Series], and Correspondence in Number 29.

† Described above, and which have proved quite successful.

Head locks.—The locks are to be 150 feet in length, and 20 feet in width inside the chambers.

169. *Western Main Canal.*—This canal, destined to convey irrigation water to the District of Shahabad, will have to carry up to the place, where the Arrah Branch is thrown off, 4,500 cubic feet of water per second for the irrigation of 1,200,000 acres: this at first sight may appear a small quantity for the irrigation of so large an area, but it must be recollected that only about one-half is cultivated with rice. The greatest demand for water is likely to be for the rice-crop; and to convey sufficient for this the canals are designed, the supply in the river at the time of the rice cultivation being always abundant.

Dimensions of Canal.—The dimensions of the canal at starting will be as follows: —Breadth at base, 180 feet; depth of water in full supply, 9 feet,* fall per mile 6 inches; side slopes, 2 . 1; at the 5th mile, the Arrah Branch will be thrown off, taking one-third of the whole, or 1,500 cubic feet per second, leaving 3,000 cubic feet per second to be carried on to the 12th mile, where the Buxar and Chowsa branches will leave the main line. From the point where the Arrah Branch is thrown off, the breadth of the canal will be reduced from 180 feet at base to 124 feet, the fall and depth of water being the same. The Buxar and Chowsa branches will take off 1,256 cubic feet per second for the supply of 335,000 acres; the quantity remaining to be carried forward by the main canal, therefore, is 1,744 cubic feet per second; the width of canal will be reduced to 100 feet base, and the fall to 1½ inches per mile.

Arrangements for regulating level of water in canal.—As the ground falls rapidly soon after crossing the road, it will be advisable, in order to avoid a long circuit which would have to be made if the contour were followed, to construct a lock on the main line of canal somewhere near the Koodra; probably just beyond it will be the best place, so as to keep the advantage of level to cross that nullah. At this lock, a waste-weir must be constructed, the level of the top of the boarding on which will be 306 00 above datum. The object of this is to impound the water for navigation when necessary, so that, when the supply coming down the canal is small, there will always be 5 feet on the sills of the head-lock. It is obvious that the top of the boarding of the waste-weirs of the first lift-lock on each of the branch canals to Arrah, Buxar and Chowsa must be of the same level; the boarding on all these weirs will be removable, plank by plank, so that the level of the water can always be regulated according to the supply coming down, the length of the weirs being calculated to discharge the full quantity at 4 feet in depth running over the crest.

Cutting at head of canal.—It will be seen, by a reference to the section, that the cutting at the head of the Western Main Canal is very heavy and that the water will not reach the surface till the 5th mile of the canal is passed; it is intended, therefore, at first to excavate the canal with a base of 50 feet only, so as to get the water out on the surface as early as possible, according as the branches are extended; hereafter the head of the canal can be widened.

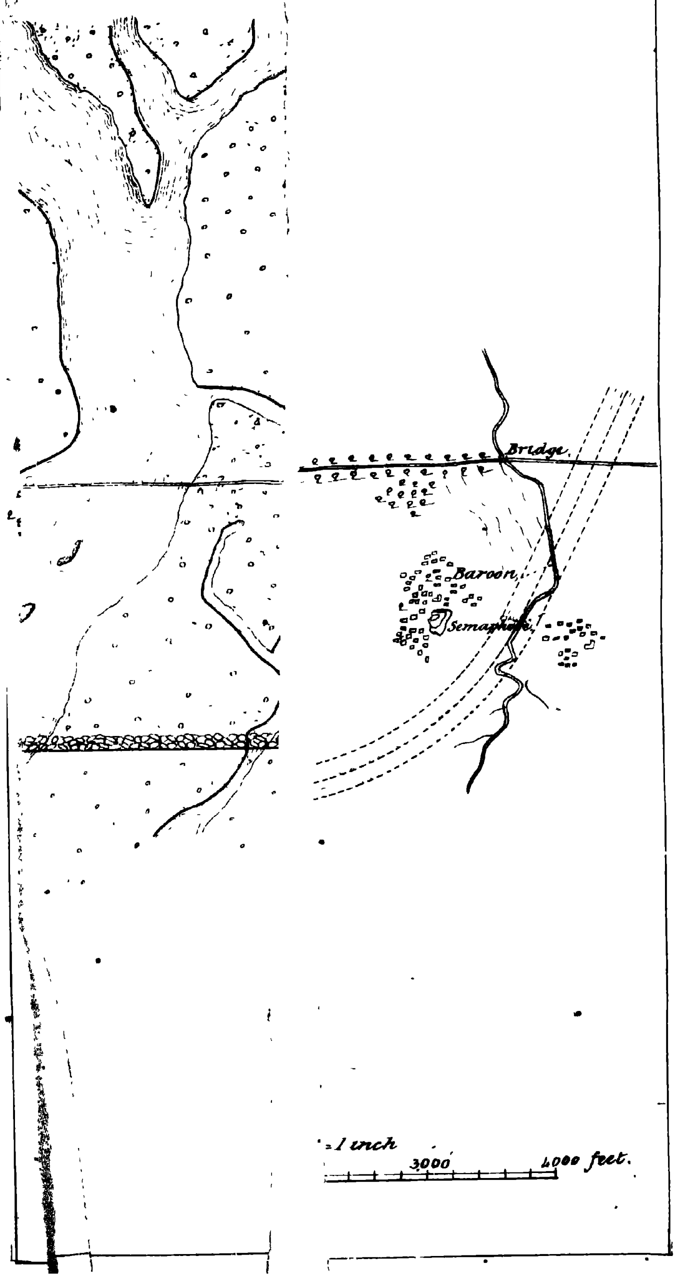
Course of canal beyond Sasseram.—As the levels from Chunar have now been connected up to the Soane at Dehree, the fact has been established that the level of the country at the foot of the hills at the former place is 50 feet below the bed of the

* The greatest demand for water will be during the rains, as above stated, at which time there will always be at least one foot of water running over the Anicut; and, therefore, 9 feet of water in the canal.

SOANE RIVER,

HEADWORKS NEAR TRUNK RO

ON THE BANKS.



river at Dehree. The course of the canal is clearly defined; skirting the foot of the hills the whole way, passing south of Chynepore, and through the rocky pass at Ghate Bhurganwan, it will cross the Kurumnassa near Kysoa, and drop into the Jurgo near Chunar.

170. *Drainage crossed.—The Kao.*—The principle drainage on the first 21½ miles of the Western Main Canal is the Kao: this nullah is subject to violent floods, as may be expected from the rocky nature of its catchment basin; there is a curious feature in this stream, viz., that before emerging on the plains, its water in times of high flood divides into two portions: one forming the Koodra runs westward, passing south of Sasseram, while the main stream of the Kao continues its northerly course: the Koodra seems to be an escape, the level of its bed being much over that of the Kao in times of high flood. About one-third of the whole stream, I should say, finds its way into the Koodra. I have thought it right to disregard this overflow, and provide water-way for the whole area drained by the Kao. The calculations for the area of water-way are founded on the supposition that two-thirds of a rain-fall of 9 inches in 24 hours will have to be carried off through the arches in that time, at a velocity of 8¼ feet per second. The area of the catchment-basin of the Kao above the canal crossing is 57 square miles, so that 1,103 square feet of water-way will be required, or, say, 20 openings of 54 square feet each.

Description of syphons.—From the level at which the stream is crossed, it will be necessary to put in syphon culverts, and as the stone in the neighbourhood is so magnificent, and procurable in such large blocks, I purpose covering the syphons over with flat stones instead of arching, securing the stones to the foundations by holding-down bolts.

Width of canal.—The width of the canal over the syphons will be reduced to 90 feet, which will give a velocity of about 3¾ feet per second.

Other drainages, inlet, and escape at 5th mile.—There are no other drainages of any importance to be provided for. An inlet and escape will be constructed at the 5th mile of the canal, just beyond the off-take of the Arrah Branch: this will drain as near as I can ascertain 5 square miles of the flat country; and, as the cultivators impound most of the water falling on the plains for irrigation, I consider it will be sufficient to allow for a rain-fall of ¼ inch per hour being carried off; this will give a length of weir of 40 feet, the water running 2 feet deep over the crest. It will be observed that the level of the ground is almost the same as the canal water; and as that entering the canal from the fields is only surface rain-water, no silt will be carried in.

Design for inlet and escape.—I have designed a drop-wall and floor, but such is hardly necessary. If the bed slopes of the canal were paved with rough stone, it would be sufficient protection against erosion; but as piers and abutments must be built to support the bridge for the towing-path, the addition of the drop-wall will be but trifling.

Inlet and escape at the 12th mile of canal.—Another inlet and escape precisely similar will be built at the 12th mile of the canal.

Two syphon culverts.—Two syphon culverts of four arches each, of the same dimensions as the Kao Syphon, will be constructed at the 870th and 1100th chain of the canal, respectively, to carry off the drainage-water between Sasseram and the canal.

171. *Bridges.—Rhotas Road Bridge.*—The head-way under all bridges on the various canals will be 15 feet. The first will be built to carry the Rhotas road over the canal at the 23rd chain; it will consist of 3 spans of 50 feet each, with a road-way 15 feet wide between the parapets.

Other road bridges.—The same design will answer for the Sasseram and Nassree-gunge Road at the 300th chain, for the Sasseram and Arrah Road at the 845th chain, and for the Sasseram and Buxar Road at the 999th chain, and for any other second class roads that it may be found necessary to carry over the canal.

Grand Trunk Road Bridge.—For the Grand Trunk Road Bridge, a similar design has been made, the width of roadway being 20 feet instead of 15; this is the width of the large bridge now being built at Sherghotty by the Public Works Department. The canal crosses the Grand Trunk Road at one mile from the head at an angle of 61°; instead of diverting the road, I have designed a skew-bridge, and considering that building material is so good, there will be no difficulty in constructing it, though the angle is somewhat sharp.

172. *Eastern Main Canal.*—The Eastern Main Canal has been laid out for 10½ miles only: it has been designed to convey water for the irrigation of the whole area to Monghyr, and to that place it must some day be extended, though at present the limits are restricted to Patna. The area of country to be supplied with water being about the same as on the western side of the Soane, the canal will be constructed of the same dimensions, depth and fall per mile.

Patna Branch.—The Patna Branch will be thrown off at the 4th mile of the canal, and will take 1,500 cubic feet per second for the supply of 350,000 acres.

Eastern Main Canal, 4 to 10½ miles.—From the 4th to the 10½ mile, the dimensions will be, base 124 feet, depth 9 feet, side slopes 2·1, fall per mile 6 inches.

Poon-Poon.—The principal drainage to be crossed is the Poon-Poon; the place selected for crossing has been carefully determined with reference to the following consideration; *first*, that the highest known floods of the Poon-Poon should not rise on the masonry of the aqueduct above the level of the bed of the canal; *second*, that the embanked approaches to the aqueduct should not be unduly high; and *third*, that the stream should be crossed at a convenient place, and square to the line of canal; to attain these objects it has been found necessary to make a considerable detour, and to go below the junction of the Byturnee and Poon-Poon.

Size of aqueduct.—The area drained by these two rivers above the crossing of the canal is 374 square miles, and water-way to the extent of 7,240 square feet should be provided to carry off two-thirds of a rain-fall of 9 inches in 24 hours (as much as is likely to fall over so large a catchment basin in that time) at a maximum velocity of 8½ feet per second; this will give 17 arches of 30 feet each; in allowing 20, therefore, ample provision has, I think, been made.

Foundations.—The foundations of the aqueduct will probably be found to be hard clay, but this cannot be positively determined till a careful examination of the bed of the river has been made and trial-pits sunk; should it on examination turn out to be sandy, wells will have to be sunk.

Width of canal over aqueduct.—The canal will be reduced to 90 feet in width over the aqueduct, as in the Kao Syphon on the Western Main Canal.

173. *Drainage near Baroon.*—The small nullah that is crossed and re-crossed by the canal near Baroon will be diverted into its old course by a new cut, and will be

passed under the Grand Trunk Road by a bridge of three 10-feet spans. The present bridge consists of 3 fifteens, which is unnecessarily large for the area of country drained by the nullah.

Drainage for bank of Soane.—The drainage water from the high ground on the bank of the Soane will be passed under the Patna Branch Canal by a syphon culvert, and led into the Poon-Poon by a side drain parallel to the main canal.

Arrah and Patna Branch Canal.—Neither of these canals has been staked out, though their course has been determined, the Arrah Branch to near Nassreegunge and the Patna Branch to Daoodnuggur. The position of the first lift-lock in each has been fixed, so that there will be no delay in submitting the plans as soon as the necessity for so doing arises.

174. *Quarries.*—The position of the quarries has been selected, and the line of tramway surveyed and levelled. It was at first contemplated to open the quarries at Muhesdeeh, but on trial the quality of the stone turned out to be inferior; it was, therefore, determined to revert to Dhadhand,—a well known quarry, where the stone is of excellent quality, and can be had in blocks of any size and thickness.

An experimental opening is now being made on the face of an outlying hill in the line of tramway to Dhadhand, and it is expected, from what has already been seen that the stone will turn out of good quality. Being only 5 miles from the anicut, I purpose getting the great mass of rubble stone from there, and the cut-stone only from Dhadhand, which is 1½ miles further

175. The actual amount for which sanction is solicited is Rs. 52,80,870, exclusive of plant; made up of the following items :—

	RS.
Anicut and head-works, ...	21,07,700
Eastern Main Canal, ...	10,26,980
Western "	15,60,550
Tramway, ...	1,55,640
Bungalows, workshops, offices, store-room, &c., ...	4,30,000
	52,80,870

The whole area under command will be about 3,600 square miles, of which 2,400 are on the west, and 1,200 on the east bank.

The culturable area is taken at 500 acres per square mile, and it is proposed to give the channels capacities suitable for the supply of half this area during the monsoon; that is, for about three-eighths of the whole area, at the rate of one cubic yard per hour per acre, or one cubic foot per second for 133 acres.

The anicut is planned on the model of the one at Cuttack, which I believe, has stood well. The Soane differs from the Himalayan rivers generally in being confined within a permanent channel, so that no flank defences of any importance will be required.

The length of the work will be 2½ miles, and the estimate, exclusive of contingencies, amounts to about Rs. 14,00,000, or about Rs. 110 a foot, which I consider very moderate.

176. It may be seen from what was said in Chapter II., of the difference between the physical peculiarities of Northern and Southern India, why the Madras system is not applicable to the former country. The Inundation Canals already described are, it is true, similar to those employed in Madras, but it would rarely be feasible to construct an anicut to secure to them a perennial supply of water, simply because the enormous expense to be incurred, owing to the great breadth of the river, and the absence of any material except brick, would not be compensated for by the small benefit secured. On this point the late Col. Anderson may be quoted (himself a Madras Officer, and who had had experience of both systems :—

" To make the conditions in the two cases at all similar, it will be necessary to confine ourselves to the ' khadir ' lands, or in other words to the tract of country along each of the rivers in the North West Provinces, which is within the inundation limit. But I have explained that the ' khadir ' land is generally of insufficient width to furnish room for a first class canal : and, moreover, the fact of the width being inconsiderable, implies that the water in the wells is influenced by the proximity of the river ; and as the cold weather level of the latter is not above 15 feet below the lip of the channel, and is less than that below the level of the ground at a little distance from it, the cultivator could never be in any straits for want of water. As a rule a great part of the ' khadir ' land is inundated during the floods, and the wheat which is sown on the saturated ground on the subsidence of the inundation, requires no further supply of water to bring it to maturity. There are generally some slight showers of rain in the winter, but at the worst, if this aid fails, the people can have as much water as they like at the depth of 10 or 15 feet below the surface of the ground.

177. " Of course the further the ' khadir ' land recedes from the river the more will the advantages above described be absent. The land will not be inundated, and the depth of the wells will gradually increase with the distance from the river. It would be difficult to define the limit at which irrigation from wells becomes unremunerative. Much must depend on the rent to be paid, but still more on the aid derived from rain. In the lower parts of the Punjab, the fall of rain is very precarious ; still there are always a few showers during the year : and in the winter there are heavy dews which must supply its place in a measure.

But taking things as they are, I should say that cultivation languished when the depth of the water in the wells below the surface of the ground exceeded 25 feet. This depth is attained at the distance of 5 or 6 miles from the river; and at the distance of 25 or 30 miles from the river, that is, on the extreme limit of the western khadir of the Sutlej, the depth is 50 or 60 feet, and in some places even more.

"Here then we have at least one tract of khadir land, which would admit of irrgation on an extended scale, and a similar strip of country exists on both sides of the Indus, both in Scinde, and in the provinces to the north of it. I am not aware of there being any other tracts of country along any of the Himalayan rivers, at all events of equal importance, in which the same want of artificial irrigation is experienced.

"The maintenance of the inundation canals is expensive, and the irrigation is partial, and dependent on mechanical aid. It would seem desirable, therefore, to ascertain if there is the means of making the supply perennial, and of constituting existing canals into branches of larger channels which might be opened at some favorable point higher up the river, and run nearly parallel to it, with the water on as high a level as might be wished.

178. "The only means of accomplishing this would be by construction of masonry works across the channels, and by extensive flank defences to prevent their being turned. The Madras anicuts have been so successful in positions, where, not many years ago, most Engineers would have anticipated nothing but failure, that one would naturally turn to them as the model to be followed on the rivers under consideration.

"The chief difficulty would be, not to give a work sufficient strength to withstand the floods, or to protect it against a flank movement of the river, but to construct it at all. The Godavery anicut was closed when there was a considerable body of water in the river, though not without great difficulty: but there were stone quarries at no great distance from the work, and the only practical difficulty was to have a sufficiency of boats, waggons, and coolies to bring the stone to the spot. But had there been no quarries, how many brick cubes would have served to make up for the want of them?

"I may remark, that unless the channel is confined within a rocky gorge, so that the width of the stream in the dry weather, is not materially less than in the rains, the simple contraction of the water-way will

not be sufficient to ensure a supply to channels on either side. Many of the Indian rivers could not be contracted by artificial works—at places where they pass through alluvial soil or sand, to much under the width of a mile, while in the dry season, the width of the stream might not exceed one quarter of a mile. On the subsidence of the river, the heads of the canals, on one side or the other, would be liable to have a sand or mudbank, three-quarters of a mile in width between them and the river; which in all probability, it would be physically impossible to cut through in time to prevent the destruction of the crops.

"It might be possible by a system of groynes, to obviate the occurrence of the serious inconvenience I have described; but they would be, at best, a very imperfect substitute for a dam, and could do nothing to raise the water when it might have fallen to an extraordinary low level.

"The construction of such a dam across that river must of necessity be a very expensive work. No material but brick would be procurable unless for coping, grooves, and other work in which stone might be considered essential, and every cubic foot of it would cost about a rupee. Even bricks would cost 14 or 15 rupees a thousand, if not more; and for the enormous quantity that would be required, it would be difficult to get sufficient fuel, at any price."*

179. *Revenue of Madras canals.*—Water-rent is not levied on these canals as in Upper India, but the land irrigated by them is charged at a higher rental, and the increase credited to the Canal Department; another great advantage enjoyed over these canals in these provinces is, that the Madras canals are opened out by degrees, while the Ganges and other canals are nearly completed before any water is thrown into them. In the one case, after an anicut has been completed, and a command over the water in the river thus obtained, the water can be turned to use by the simple excavation of channels in different directions. The depth of excavation at the heads of the main channel may be considerable, but it is generally practicable to excavate them to the capacity required to deliver a supply of water sufficient for the immediate wants of the district, during the period occupied by the construction of the anicut which will

* For the tract above described a project for a dam to secure a perennial supply to the Upper Sutlej Canals was prepared and sent to Government some years ago. Nothing has yet been done however. It was suggested by Col. Dyas, then Director of Punjab Canals, that such a dam might advantageously be combined with the Railway Bridge which was then projected in that neighbourhood.

probably not exceed 3 years. Sluices and other masonry works will be required also, but on some if not all of the projected lines of channel, their progress will keep pace with that of the anicut; and there are generally existing channels,—natural or artificial,—which may be used temporarily, if not permanently, to distribute the water in different directions.

Further, in every part of the Madras Presidency, there are a number of rain-fed tanks, the revenue derived from which may be liable to undergo extraordinary fluctuations, owing to the uncertainty and insufficiency of the supply. The cultivation then becomes a lottery; it may be profitable or it may not; but the cultivators, though they may be ready to run the risk of losing a portion of their crops, will be obliged to refrain from cultivating all the land under their tanks, though if they could secure a good season, they would be only too glad to do it. The addition of the water supplied by means of the anicut channels to such tanks, would have the immediate effect of securing the revenue and of giving confidence to the people.

Even with an expenditure of 20 lakhs of rupees, which is more than would be required to bring an anicut and channels on a large scale into operation, it will be readily understood that an increase of revenue sufficient to constitute them remunerative works, or a return of 5 per cent. might be realized almost in the very first year, during which a supply of water is provided. Direct irrigation by means of small channels would be carried forward at the same time; and as the demand for water increases, there is comparatively little to be done, beyond increasing the capacity of the main channels for a few miles from the heads.

Thus, the Delta projects in the Madras Presidency provide in the first instance for the supply of water sufficient to place existing cultivation in a state of security, and for a moderate extension of irrigation to new land; but they admit of expansion, until they comprehend the whole of the country which can be brought within command of the water. The system must be considered to be practically a very perfect one.

CHAPTER XI.

IRRIGATION TANKS.

180. A TANK for irrigation is formed by an embankment thrown across a line of Drainage so as to collect the water on the upper side, which is then drawn off for Irrigation purposes by means of sluices and channels.

Tanks are of several kinds. 1. Where a bund is thrown across the gorge of a mountain pass which is the bed of a torrent, thus forming a lake enclosed by the rocky sides of the pass.

2. Where a natural hollow in the ground outside the hills is made into an artificial lake by closing up all places where the water can make its exit; such a hollow may be a very small, or may be a large natural basin drained by a stream or nullah; and the supply for such tanks may depend entirely on local rain, or on streams swollen by rain in the hills above. Or, as is often the case, the tank may be filled by a cut from a neighbouring stream, not running through it.

3. Where artificial side walls are required as well as the front wall, to enclose the water—in consequence of there being no natural hollow, but merely a continuous slope of the ground in one direction.

It is evident, however, that these three kinds are merely modifications of each other, depending on similar principles for their construction, and which may be treated of collectively.

181. In designing a tank, when the source of supply has once been ascertained, the first point to be determined is the position of the bund by which the tank will be formed. Other things being equal, it is evident that the narrowest part of the gorge or hollow should be chosen, so that the length of the embankment may be as short as possible—and in most cases this will be found to be the best site. But it is also to be looked to that this bund shall hold up the greatest quantity of water possible, and this may in some cases modify the actual site of the embankment. It is evident that the amount of water so held up will

depend on the area covered by the water and its depth. This depth again will depend on the height of the embankment and the slope of the bed of the tank—for the water can nowhere rise higher than the lowest part of the top of the embankment (natural or artificial) which dams it up, but will then, if the supply be continuous, escape at that point. Sometimes, therefore, it will be found that a bund at some other spot than the narrowest may give a larger area or greater depth above so as to hold up such an additional quantity of water as will amply repay the cost of the increased length of the bund.

Other points to be taken into consideration in selecting a site for an embankment are, the relative level and position of land to be irrigated, the quality of soil for foundations, and the proximity of stone and lime, fuel and water, for the supply of the works when in progress.

182. Briefly, the indications most favorable to the construction of a tank-embankment may be thus enumerated:—1st, A channel bringing down an ample supply of water; 2nd, For the bed of the tank, a broad expanse of nearly level land in front of the embankment, having a slight dip towards the latter; 3rd, That the land to the rear be of greater extent than the bed, and slightly lower in its level, in order that every portion of it may be irrigated through masonry sluices constructed in the embankment, and communicating with earthen channels leading to each field; 4th, A rocky foundation at little depth from the surface; 5th, That water be procurable from the bed of the water-course, or from a well, for the use of the work and work-people; 6th, That stone, lime, and fuel be within reasonable distance.

It will rarely happen that all these advantages are offered at one locality. The main object of the tank, it is to be recollected is the irrigation of the land to its rear. A careful survey of the proposed site should be made, including the levels of the intended dam, and of the land to its front and rear. The elevation of the embankment, and the area of the bed to be submerged, may then be adjusted and determined, and an opinion as to the irrigative powers of the tank, in reference to its depth and expense, may be formed. The expense of the work is then to be contrasted with the probable return from the irrigation of the land in rear, from the growth of luxuriant crops in the bed after the withdrawal of the water, and from the more indi-

rect benefit arising from the multiplication of wells supplied by filtration from the tank.

183. It next becomes necessary to determine in what way the surplus water that may be thrown into the tank shall escape. If there is perfect control over the stream by which the tank is fed, the water may be turned off when the latter is full, by means of a sluice at the head. This, however, will not often be practicable, and in any case, an escape must be provided from the tank itself for the surplus water. This may be allowed an exit in two ways; either by the dam itself or by a side channel, arranged so that the surplus water shall flow down it as soon as it comes nearly on a level with the top of the embankment. If such a channel can be provided at a moderate expense, it is always the preferable method, as there is then no danger to the dam from the shock of water falling over it—nor of silt or boulders accumulating in the tank, nor of the irrigation channels and sluices being injured.

But in many cases, especially where the tank is formed inside the hills, the expense of cutting such a side channel would be too great, and the only passage for the side water must be by the dam itself. To effect this, flood-gates must either be provided, or the water must pass over the whole or part of the dam. In peculiar cases, the former method may be allowed, but as a general rule, the latter method is preferable, as being self-acting. If the dam is of no great length, and can be made of solid masonry throughout, then the whole of it can be arranged as an overfall. If so large an escape is not required, and the embankment is of earth for the greater portion of its length, then a portion of the dam must be built of masonry (the top being two or three feet lower than that of the earthen embankment), and will serve as an overfall or waste weir.

184. Such are the general principles of these works—we may now enquire further into the details of their construction.

The thickness of the embankment must of course depend on the nature of the material, as well as on its height, and the violence of the stream that has to be arrested. In damming up a hill torrent, boulders will generally be found in sufficient plenty to yield abundance of lime and stone, and if fuel is cheap and water at hand, it would be better to make the whole bund of pucka boulder masonry. If not, then the portion forming the overfall must at any rate be so constructed, and the remainder may be made of dry boulders with a long slope on each side

and a thin pucka wall in the centre to prevent leakage. The thickness should of course decrease from the bottom to the top, and that portion over which the water is to pass, especially if it is to be of any great height, should be raised bit by bit, in successive seasons, and the water be allowed to flow over it freely. It will thus have time to consolidate, and its strength be satisfactorily tested. The foundations should be carried down to rock if possible—or at least to firm soil. If this is not found at a moderate depth, an artificial foundation of concrete or rubble masonry may be formed. The superstructure should be carried into the side rocks to prevent their being turned. The shape of the waste-weir may be perpendicular on the water side, with a long slope behind for the water to flow over, and the flooring protected in the usual manner. Additional strength is sometimes given to such massive embankments by throwing out bastions, at intervals, on the water side. One or two of these can be made hollow to contain the sluice which can be worked from the top, and spiral steps may be made inside to descend into the water.

185. Where the supplying water is less violent, and in the case of tanks outside the hills, such extraordinary precaution and solidity of workmanship are of course not requisite. Boulders, too will be scarce or perhaps wanting altogether,—so that earth, bricks, and perhaps brushwood and piles, will have to be the materials employed. The earthen embankment must of course be made very massive, and if it can be protected from the action of the water by a thin wall of pucka brick masonry or dry stone it will be as well. If not, it should be well turfed or defended with piling and wattling. Of course no part of the earthen embankment can be used as an overfall, but if there is no separate escape for the surplus water, a portion of the embankment itself must be made of masonry to act as an overfall.

186. Annexed is a Plate showing the sections of several famous Dams, and a calculation is given of the necessary thickness to be given to one of them, which will serve as an example for others of a similar kind elsewhere.

Calculations showing the Stability of the Masonry dam across the River Moota.

Extreme depth or head of water, during heaviest flood, 85 feet.
Height of dam, without parapet, 88 feet.

Thickness at base = 0·55 of head of water.

Thickness at highest water or flood level = 0·25 of thickness at base.

Batter on water face = $\frac{1}{20}$th of height.

Batter on rear face = $\frac{4}{11}$ths of height.

Weight of one cubic foot of water = 62·32 lbs.

Weight of one cubic foot of masonry = 150 lbs.

First, to find the centre of gravity of the figure.

The centre of gravity of the paralellogram ABEC is at P its centre, and 44 feet, or half the whole height, from the base.

The centre of gravity of the triangle BED is at Q, which is one-third of the whole height, or 29·33 feet from the base.

Join PQ, and through Q draw the horizontal line HQ; from P let fall the perpendicular PF, to meet HQ in F.

Then to fix the position of O, the centre of gravity of the whole mass of masonry, we have—

$$\begin{aligned} \mathrm{PO} \times \mathrm{ABEC} &= \mathrm{QO} \times \mathrm{BED} \\ &= (\mathrm{PQ} - \mathrm{PO})\,\mathrm{BED} \ldots\ldots\ldots\ldots\ldots \quad (1) \end{aligned}$$

By finding the value of PQ, and the areas of ABEC and BED, we shall obtain the value of PO, and then of OQ.

$$\begin{aligned} \text{Now } \mathrm{PQ} &= \sqrt{\mathrm{PF}^2 + \mathrm{FQ}^2} = \sqrt{(\tfrac{\;}{2} - \mathrm{JL})^2 + (\mathrm{HQ} - \mathrm{HF})^2} \\ &= \sqrt{(14{\cdot}66)^2 + (22{\cdot}62 - \{2{\cdot}93 + \tfrac{1}{2} \times 10{\cdot}56 - \tfrac{1}{2} \times 4{\cdot}4\})^2} \\ &= \sqrt{490{\cdot}8} = 22{\cdot}15 \end{aligned}$$

Next the area of ABEC = 10·56 × 88 = 929·28

and the area of BED = 18·1 × 88 = 1592·80

Substituting the values now found in equation (1), we have—

$$\mathrm{PO} \times 929{\cdot}28 = (22{\cdot}15 - \mathrm{PO})\, 1592{\cdot}8$$

$$\text{whence } \mathrm{PO} = 13{\cdot}98.$$

$$\text{and } \mathrm{OQ} = \mathrm{PQ} - \mathrm{PO} = 22{\cdot}15 - 13{\cdot}98 = 8{\cdot}17.$$

The weight of the whole mass of masonry, assuming that one foot in length of the dam is taken into consideration, will be

$$2522{\cdot}08 \times 1 \times 150 \text{ lbs.} = 378312{\cdot}00 \text{ lbs.} = W,$$

and it may be supposed to act at N in the vertical line dropped from the centre of gravity of the whole mass, O. The pressure of the water will be

$$85{\cdot}1 \times 42{\cdot}5 \times 62{\cdot}32 \text{ lbs.} = 225395{\cdot}86 \text{ lbs.}$$

and will act at M, at a distance of one-third of the whole depth from the bottom, and in a direction perpendicular to the face of the wall.

This force may be supposed to act at N, where its direction is intersected by the vertical ON.

To facilitate the working out of the result, resolve the pressure of the water, which may be called P, into two forces; one, W′, vertical; the other P′, horizontal, at N.

Complete the parallelogram NVTU.

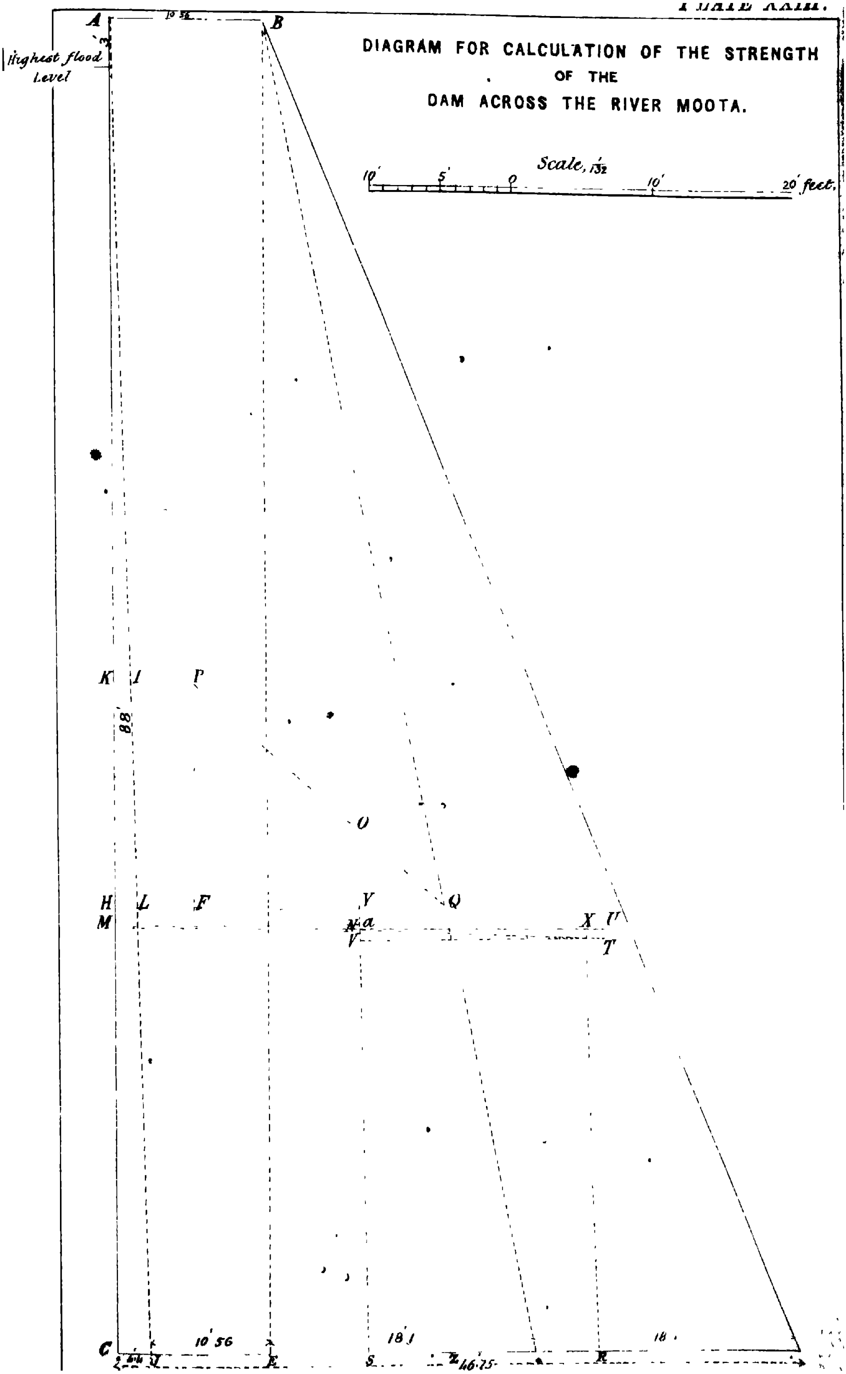
Then NV = TU = NT sin TNU.

$$\text{Now } \sin \mathrm{TNU} = \sin \mathrm{CAJ} = \frac{4{\cdot}4}{88{\cdot}11} = 0{\cdot}05$$

$$\text{Therefore } \mathrm{NV} = 0{\cdot}05 \times 225395{\cdot}86 = 11269{\cdot}79 = \mathrm{W}'.$$

$$\text{and } \mathrm{NU} = \mathrm{P}' = \sqrt{(225395{\cdot}86)^2 - (11269{\cdot}79)^2} = 225113{\cdot}93.$$

DIAGRAM FOR CALCULATION OF THE STRENGTH OF THE DAM ACROSS THE RIVER MOOTA.



The forces acting at N will thus be W + W′ in the direction of the vertical OS, and P^1 in the direction NU.

Complete the parallelogram NSRX, making NS and NX proportional to the forces W + W′, and P^1 respectively.

$$W + W' = 378312{\cdot}00 + 11269{\cdot}79 = 389581{\cdot}79.$$
$$\text{and } P^1 = 225113{\cdot}93$$

Now $SN : SR :: W + W' : P^1 :: 389581{\cdot}79 : 225113{\cdot}93.$

$$\therefore SR = \frac{SN \times 225113{\cdot}93}{389511{\cdot}79}$$

and $SN = SY - NY = 29{\cdot}33 - (Ya + aN) = 29{\cdot}33 - (1 + aN)$

Again $aN = \frac{1}{20} \times aM = \frac{1}{20}(HF + FY + \frac{1}{20} \times 1)$

$$= \frac{1}{20}\left(5{\cdot}28 + \frac{44 - 29{\cdot}33}{20} + FY + \frac{1}{20}\right)$$

and $FY : FQ :: PO : PQ$

$$\therefore FY = \frac{FQ \times PO}{PQ} = \frac{16{\cdot}61 \times 13{\cdot}98}{22{\cdot}15} = 10{\cdot}48$$

$$\therefore aN = \frac{1}{20}(5{\cdot}28 + 0{\cdot}733 + 10{\cdot}48 + 0{\cdot}05) = \frac{16{\cdot}543}{20} = 0{\cdot}8271$$

$$\therefore SN = 29{\cdot}33 - (1 + 0{\cdot}8271) = 29{\cdot}33 - 1{\cdot}8271 = 27{\cdot}51$$

$$\text{and } SR = \frac{SN \times 225113{\cdot}93}{389581{\cdot}79} = \frac{27{\cdot}51 \times 225113{\cdot}93}{389581{\cdot}93} = 15{\cdot}63$$

$$\text{Now } CS = HY + \tfrac{1}{20} \times SY = HF + FY + \frac{29{\cdot}33}{20}$$

$$= 6{\cdot}013 + 10{\cdot}48 + 1{\cdot}466 = 17{\cdot}959$$

$$\text{and } CZ - \tfrac{1}{2}\ CD = \frac{46{\cdot}75}{2} = 23{\cdot}375$$

$$\therefore SZ = 23{\cdot}375 - 17{\cdot}959 = 5{\cdot}416$$

$$\text{and } ZR = SR - SZ = 15{\cdot}63 - 5{\cdot}41 = 10{\cdot}22$$

The resultant R, therefore, passes through the base at a little less than one-fourth the width of the base, which is 11·69 from its centre.

Rankine, who is perhaps our best authority on the subject of the stability of retaining walls, or dams, says, that except when the foundation is rock, one-fourth of the width of the base from the centre is the limit for the resultant, but that in the case of a very firm foundation this limit may be exceeded. It has, however, been thought advisable to give the dam for the Moota Reservoir some extra strength, and the resultant passes even within the limit laid down by Rankine for a dam on an ordinary foundation though the Moota Dam will be founded on rock. No credit, moreover, has been taken for the aid that will be obtained from the bank of earth which will be heaped against the dam on both sides to check leakage.

The weight of a cubic foot of masonry has been obtained by actual experiment on rubble stone walling at Poona.

187. The Barrage d'Almanza was constructed in the 16th century, and is in excellent condition, which proves the general soundness of the design.

The Barrage de Gros Bois is also an old work. It has shown signs

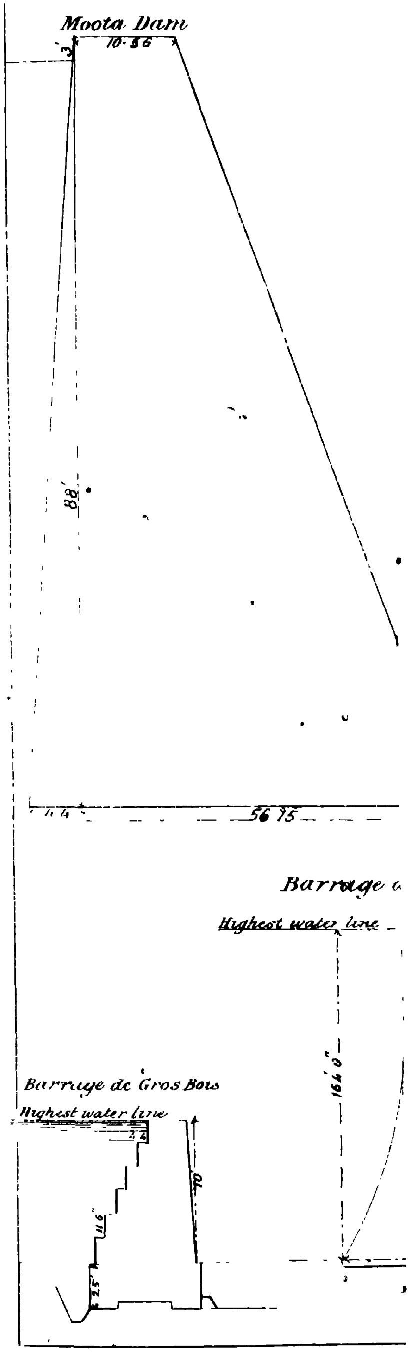
of failure and has been buttressed. The batter in this case is on the water side, and the section is recommended in the "Aide Memoire." It may be well adapted for an ordinary foundation, as its tendency to oscillate on a yielding foundation when the reservoir is alternately full and empty, may be less than when the batter is outside, but it is not well suited when a hard foundation is attainable, and where a great height of Dam is necessary.

The Barrage du Furens is a recent work. Its height is 164 feet. The great pressure induced by such an immense column of masonry and water led the very ingenious Engineer, M. Delocre, who designed the Dam, to adopt the principle of equal pressure, and hence the curved faces and comparative lightness of the superior part of the section, which, at first sight, would appear almost too weak to retain the great head of water to which it is exposed. The thickness at top would no doubt have been still lighter, but that it was necessary to guard against the effect of the ice, which in that latitude attains a thickness of about 2 feet, and when broken up by a sudden thaw, is driven by the prevailing wind with great violence against the masonry, which has thus to bear the most severe shocks, in addition to the ordinary action of the waves.

The Barrage du Ban is another, and more recent design, on the equal pressure principle. It differs from the Barrage du Furens in having a higher pressure limit. The lower part of this profile is intended to show what the form would have been, had the height of the Dam been exactly equal to that on the Furens.

188. *Madras Tanks.*—The banks of the majority of tanks in Madras seldom exceed 5 yards in height. Some of them are however 40 or 50 feet high, and even more. Many of them are formed of earth only, in a few instances carefully turfed; while the larger works, and in countries where stone is abundant, many of the smaller banks also, are protected by loose blocks of rough stone laid on the inner sloping surface, or disposed in the form of a nearly upright revetment, without mortar or cement. The object of these rough stone facings is not so much to support the earthwork, as to protect it from the action of the waves during stormy weather, and from damage by the monsoon rains.

Many tanks are often formed in the same valley, the bed of one beginning where the cultivation under that above it ceases. In consequence of this, the breaching of one tank often leads, by the sudden


Moota Dam
10·56
3'
88'
14
56·75
Barrage
Highest water line
164' 0"
Barrage de Gros Bois
Highest water line
2·4
70
11·6"
2·5"

influx of its waters to the bursting in succession of those below it. This is more particularly the case, when heavy and sudden rains succeed seasons of drought, during which, the earth of which the tank banks are composed, loses its tenacity and is soon saturated by water. Another, and the general cause of the breaching of tanks is the neglected state of their banks, which are not in all parts sufficiently raised above the surface of the water in them. High winds exciting waves in the tank. throw the spray over the lowest parts of the banks, which are thus gradually worn away, until at last the water overtops them, and a breach ensues.

189. In Madras, the waste weirs above described, are known by the name *Calingulah*, a Tamil word of originally much wider import. Along the upper surface of these, a row of upright stones two to four feet apart, and from two to eight feet high, are generally inserted. The intervals between these stones are filled up with earth, straw, and rubbish, to increase the capacity of the tank when the rains are moderate; but when the supply of water is too great, and the tank is in danger of being breached, the interstices are cleared, to allow a larger quantity of water to escape, the rapidity of the outflow being increased by the additional vent thus afforded. The dam-stones are made of such height, that the top of the temporary bank raised between them is nearly on the highest level to which water can rise in the tank without endangering its bank. The use of these stones is however generally considered objectionable, as the interstices are not always cleared at the proper time, and in some cases, sluice gates have been substituted. In some tanks, the excess of water flows out from vents pierced at a low level in masonry walls similarly placed. These vents are closed by vertical planks, inserted side by side, or by shutters. Works of this description, termed *surplus sluices*, allowing the water to flow out with greater rapidity, are of smaller dimensions and less expensive than calingulahs. Vents to be closed by planks or shutters have frequently been constructed in the lower part of the body of calingulahs. But the common calingulah is in the usual way of allowing the surplus water of tanks to escape.

190. The velocity of water issuing from an opening such as a calingulah depends upon the height of the surface of the water escaping above the bottom of that opening, and is found by multiplying the

square root of that depth or height by 5, and the height being in feet, the velocity will give the feet per second; thus the height being 4½ feet, the velocity will be $5\sqrt{\frac{9}{2}} = 15\sqrt{\frac{1}{2}}$: this multiplied by the product of the height and length, will give the discharge. Knowing, therefore, the quantity of water that can enter the channel or tank in an hour, the length of calingulah is easily found: thus, it is found that for the extreme fall of rain on only one square mile, a calingulah of 120 feet is required, supposing the water flowing out to be of the usual depth, that is 4½ feet, which is about the average height of calingulah dam stones in moderate sized tanks. Were the depth to be greater, the discharge for the same length would be increased, and in a greater proportion, viz., that of the square root of the cube. Thus if the depth were multiplied by 2, the discharge for the same length would have to be multiplied by $\sqrt{8}$, and so for an equal discharge. A depth of 9 feet of water would allow of the length of the calingulah being reduced to a little more than ⅓ of the length required when the depth was only 4½ feet: so that if a tank bank be so high that it will be safe when 9 feet of water goes over the calingulah, 40 feet will be sufficient for every square mile of drainage. But this is an enormous length; it is not unusual for a tank to receive the drainage of a country from several miles round; and if 30 square miles, or a quarter of a circle of 13 miles radius drained into a tank, by this rule it would require no less length of calingulah than 1,200 yards in the former case, and 400 in the latter, while there are no tanks having calingulahs approaching these dimensions.

191. We must therefore inquire into other parts of this important question; and in the first place, we have hitherto proceeded upon two extreme suppositions which can rarely occur together, viz., 1st, That the tank is full before the heavy fall of rain commences; and 2ndly, That 5 inches of rain-fall in one hour, or at the same rate; as records have shown it to have fallen in 12 minutes only. The length of calingulah necessary would have to be reduced in proportion as the fall of rain is less rapid; and if 120 feet be required for 5 inches an hour, 60 will suffice for 2½ in the same period; or if the water can for a short time be 9 feet above the floor of the calingulah, 40 feet per square mile will do for 5 inches, and 20 feet for 2½ inches per hour. With regard to the first supposition, it is most likely that the tank will not be full when the heavy rain occurs; and in this case the greatest part of the

water would be retained in the tank; thus if the bed of a tank contain 5 square miles, and it receives the drainage of 20 square miles (the total fall of rain not exceeding 50 inches in a year), the tank would not overflow if capable of containing 4 times 50 inches, or 16 feet 8 inches over its whole surface; or if the bed of a tank be in any proportion to its drainage, water will not flow out until the number of inches of rain fallen bears the same proportion to the average depth. It is evident, therefore, that the proportion that the tank bears to the surface of the land which drains into it, must also be taken into consideration, and the dimensions of the calingulah regulated by all the circumstances which affect the supply of the tank and the quantity of surplus water. To most large tanks the water is brought from rivers by channels, and the quantity of supply may (in that case) be regulated by a head sluice.

One of the largest calingulahs in Madras is that of the Carangooly tank, in the Chingleput district, and is of the form and dimensions of the annexed plan: it was built by General Sir J. L. Caldwell, of the Madras Engineers, many years ago.

192. *Sluices of Irrigation.*—Each tank is provided with from one to two, and some times three sluices, by which the water can be let out to the fields at pleasure. Their position is generally on a level with that of the bed of the tank, but if any portion of the lands to be irrigated be above that level, one or more of the sluices, is placed at a corresponding height. A tank sluice is a large substantial and not unfrequently an expensive work; it consists of a 2 yard square brick or stone cistern one yard high, to keep off the sand at the front of the bund, with one or more valves or plug-holes, in a stone at the bottom, from 6 inches to a foot in diameter. The valve is attached to a pole so long, that the top shall never be covered with the water in the tank. It is held in an upright position by 2 or 4 vertical stone pillars from 9 inches to ½ a yard square, to which horizontal stones are attached, one at top and another midway, down through a hole in the centre of which the valve rod works, having a stout chain and pin to uphold it when necessary, and to regulate the discharge; the pressure of the water upon the top of the valve keeps it sufficiently tight when lowered into the valve hole to prevent the escape of the water. At the rear of the bund another cistern of about the same dimensions and usually of brick in chunam is built, three sides of which are furnished with square open-

ings and shutters, to admit of the water being turned off in the required direction. The two cisterns are connected with a tunnel, the length of which depends upon the cross section of the bund through which it is laid, and is generally from 10 to 30 or 40 yards. The vent throughout the tunnel, for the passage of the water, is about 2½ feet high, and 2 feet broad. These dimensions are adopted to permit of a man going in to clear away obstructions, and to examine the state of the tunnel occasionally, should anything appear to have gone wrong. The cross section of a tunnel is like that of a massive barrel-brick-drain, but the vent is generally rectangular and cased with granite slabs about 6 to 9 inches thick.

More elaborate contrivances are used on the Tanks in Northern Italy, which will be found described in Irrigation Tract, No. II., published at Roorkee.

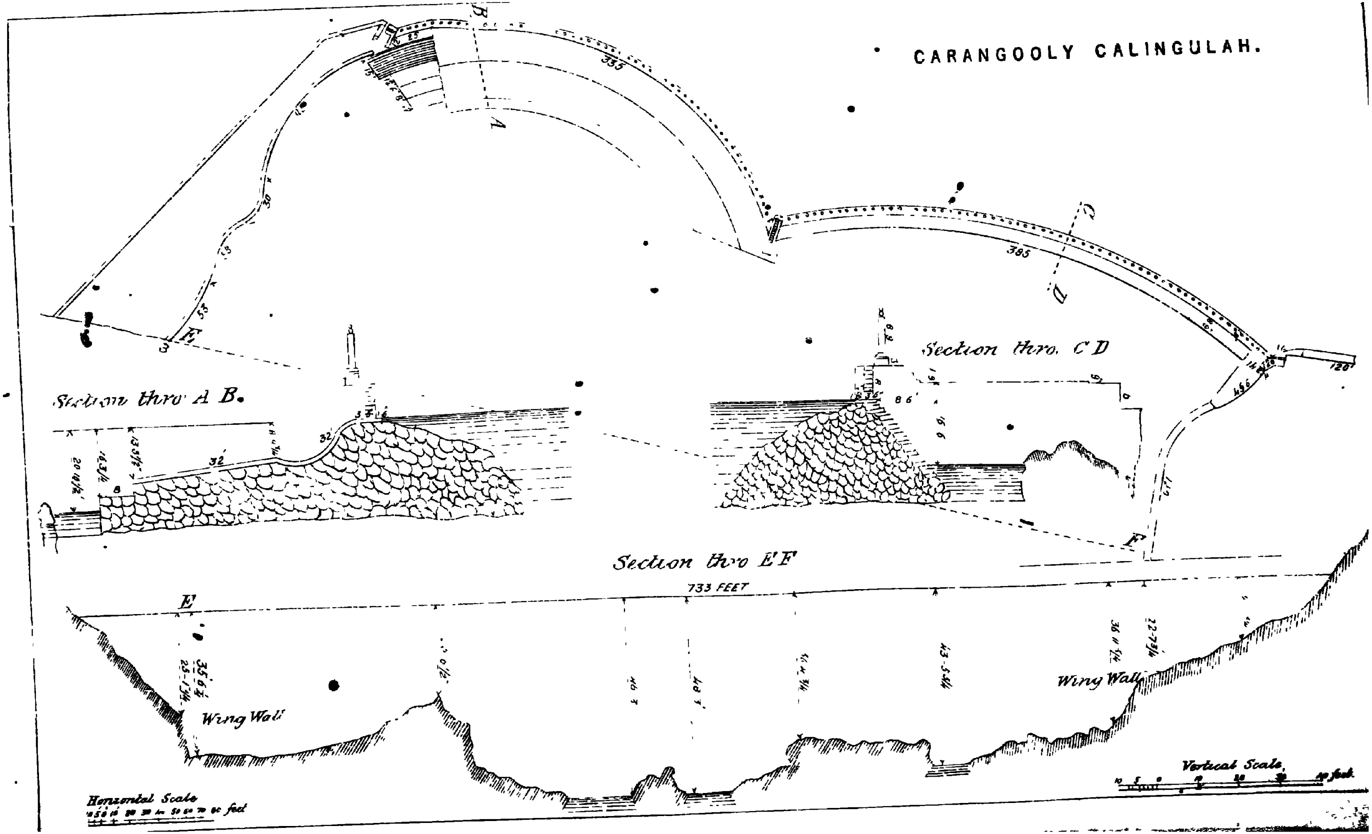
Irrigation by tanks is often combined with that by rivers, the water from the rivers being brought into tanks that are favorably situated, by means of channels cut through the river bank and intervening ground.

193. The following description of the Mysore tanks by Captain (now Major-General) Green, will be found interesting:—

" *Tanks.*—There are upwards of 20,000 tanks in the returns, the bunds of which are of every variety of length, from a quarter of a mile to 1½ miles. They are with very few exceptions, faced with a rough stone revetment, having a batter of about one horizontal in two vertical; the stone facing averages from a yard to half a yard in thickness, and is backed with loose rubble stones, which are together of a thickness equal to that of the large stones in front. Occasionally, a lighter description of revetment retains the rear slope of the bund. The breadth of the earthwork is proportioned to its height, which is greatest in the centre of its length. An ordinary bund is about 12 feet broad at top, 60 feet at bottom, and 18 feet high: there are many in every Talook, however, which exceed the above section.

Codies.—In addition to the sluice above described, each tank is provided with from 1 to 4 open masonry outlets, called codies, the gorges of which vary from 10 to 100 yards in width, and by which the surplus water of the tank escapes to other tanks below. As the rush of water over the codies would wash away any but a strong description of work, by which it was confined in its passage from the tank, the codies are necessarily made very substantial with the largest sized rough stones procurable in the neighbourhood, those of the large tanks rivalling the smaller anicuts on the rivers in the massiveness with which they are constructed, and the brick retaining walls with which they are frequently protected. Codies are generally of a square figure, covering as much ground lengthways, as in their width. The front, which breasts the water, consists of a solid rough stone wall from 1 to 2 or 3 yards deep, according to the quality of the soil, and of proportionate thickness. It is furnished with dam-stones, which project a yard and a half, and are let firmly into the top of the wall at 1 yard

CARANGOOLY CALINGULAH.



intervals. The addition of some sticks, straw, and turf placed in front of these vertical stones make a temporary dam, by which the ryots are enabled, after the burst of the monsoon is over, to retain the water in the tank at a level about two feet higher than they otherwise could have done, and to secure the water for a so much larger period.

"The sides of a cody are protected by wing-walls 1 to 2 yards high, of rough stone or brick-work which, contract or approach one another at the ends of the gorge wall, and widen out above and below forming, as it were, the sides of the funnel of discharge.

"The stones on the lower of the gorge wall, are usually laid over suitable foundation in the form of a sloping apron, from its top to the bottom of the nullah below, by which the force of the water is broken; in cases, however, where it is found difficult to render this (the ancient mode of building codies) permanent, recourse has been had to disposing of the apron stones like a flat pavement at the foot of the gorge wall (whatever be the height of the latter) taking care to have a very solid iron clamped platform of cut stones for the water to escade upon. Its force is there expended, and it flows gently away from the foot of the gorge wall without having the power to do any mischief; this plan is found most effectual, and has never failed wherever it has been tried.

"The level of the top of the cody, whether of the permanent masonry or of the low temporary dam now occasionally put above it, is the gauge of the powers of capacity of the tank; above that, the cody is always open and acts as the safety valve of the tank.

"In the nullah, immediately below a cody, is sometimes built another work of rough stone like the cody, and equally large, but which so applied is termed a "cuttay." Taken off from above the latter, is a channel of irrigation. This is a very good arrangement when the levels are favorable. The cody retains the water in the tank at its highest safe level; the cuttay below appropriates the surplus water, which the cody has discharged, and which but for such cuttay would be lost. Pouring over the cody in a thin sheet of perhaps a few inches only in depth, the sectional area of the water is fully sufficient to supply an ordinary tank channel of irrigation, and when it ceases, recourse is had to the sluices in the bund which are then opened. As the surplus water for 10 or 15 days annually is discharged in a great volume over the codies, the cuttays below are then exposed to a great shock from the impulse thereof and require to be substantially constructed.

194. "As the alluvial deposit, year after year accumulating, gradually raises the beds of tanks, they would in process of time become useless, were not the alternative adopted from time to time of adding to the height of the bunds, which of course involves an enlargement of the cross section generally, as well as the raising of the codies and the construction of new sluices at higher levels than the former ones occupied, when the sand has eventually choked them up.

"Thus, even if no breaches occur, there is a constant yearly increased demand for tank work, and several of the bunds have attained height in the effort to keep them sufficiently above the surface of the water. The upper part or roadways of several bunds in each of the four Divisions, are on a level with the tops of the cocoa-nut, and even of the more lofty areca, trees, in the gardens immediately below them.

"The same resource is had recourse to in discharging the sand from the tank beds, that is adopted for the ejection of that carried into the channels of irrigation from

the rivers. But a different season is selected ; instead of the close of the monsoon, its commencement is taken, and no sooner is it seen that the monsoon has set in, than the ryots range themselves about the sluice head in the tank, which is at this time shallow, and stir up and agitate the bed, till, reduced to a semi-liquid state, it runs off through the sluice with the water. This, like the opening of the nullah under-sluice, it however but a partial remedy. It is less expensive to raise the bund than to carry away the sand by hand.

195. "Most tanks receive their supply from the high ground in the neighbourhood, and irrigate paddy fields or gardens immediately below them ; but there are exceptions to this, as numerous tanks are partly supplied by channels winding round more remote hills, and which catch all the rain water flowing down their sides and convey it into the tank. Water courses or nullahs which are called into existence during a local fall of rain, are also dammed up, and their contents in like manner appropriated to the benefit of tanks. A single tank may possess several feeders of this kind, all of which require to be kept in repair.

"In like manner the fields to be irrigated are occasionally at a distance from the tank, and have channels of irrigation therefrom, including their windings, of from 2 to 30 miles long, and upon the preservation of all of which in proper order, depends the success of the crops. The water of the Soolikerry lake irrigates land at a distance of 30 miles. Other reservoirs of water, not connected with the irrigation, but such as public wells, bowries, cuttays and so forth, which are required for the use of the inhabitants and their cattle, have been extensively restored in every Talook in the country ; and the consideration of the Government in directing these improvements of works so essential to the health and comfort of the community, is rightly appreciated and gratefully acknowledged.

196. It is calculated in Madras that a cubic yard of water is required for every square yard of land having to be irrigated constantly through the year. This appears to be a large amount, but in the absence of more certain data it may be used in estimating the probable return of a tank.

Rice land requires to be covered throughout with water to a depth of half an inch ; seventy-two days are calculated as the time required by the land to be covered with water ; therefore for a *cawnie* of land, (6,400 superficial yards,) 6,400 cubic yards of water should be stored for every cawnie which is to be watered.

A channel should supply $\frac{6400}{72} = 88\frac{8}{9}$ cubic yards per diem, or $3\frac{19}{27}$ cubic yards per hour for every cawnie to be watered.

It is usual, in calculating the water required for a cawnie, to allow 10,000 yards, which allows for evaporation, wastage, absorption, &c.

$88\frac{8}{9}$ cubic yards = 2,400 cubic feet per diem = 100 cubic feet per hour, and requires a vent of $\frac{1}{10}$ of a square foot at the velocity of 1,000 feet an hour ; at one mile an hour, it requires $\frac{10}{528}$ of a square foot.

For 440 cawnies of rice land, equal to one square mile, water running

at the rate of one mile an hour will require a vent of $\frac{4400}{528} = 8{\cdot}3$ square feet.

Not much attention, as a general rule within certain limits, appears to be given to the size of orifices for the discharge of water for irrigating land under tanks. The sluices are pretty numerous, because some lands are higher than others, and again belong to different villages, and a little practice enables the person whose business it is to distribute the water, to judge what amount of opening is required.

197. The tank system of irrigation so common in lower India is comparatively rare in the Upper Provinces. Indeed the only districts where it has been carried out on a great scale, the principle having been applied by the Natives from time immemorial, are those of Mhairwara and Ajmere, where Colonel Dixon's energetic attention to the subject produced most successful results.

The districts that lie at the foot of the Hills on the E, N. E., and W. of the Punjab would, however, seem to be peculiarly adapted for it. Rain is scarce, the hill streams are numerous, and the soil in general of good quality A system therefore by which the temporary supply of water from occasional rain might be stored up for future use, is one that is deserving of serious attention.

In the Punjab, the tank would sometimes be filled twice a year—about the months of February and July—and would irrigate both crops. In other parts, especially on the Western frontier, where very little rain falls in the cold weather, it would often happen that the water would be available for the *Khureef* only. The bed of the tank might in this case be sowed when dry in the autumn, for the spring crop—as the soil would be wet and probably rich from the silt deposited in it.

198. On the Western frontier of the Punjab, were rain is excessively scarce, and the ground near the Hills at so high a level that it is impossible to irrigate it either from Wells or Canals,—the natives are very ingenious in turning the water that occasionally comes down the hill nullahs to good account. The dry bed of the stream is taken possession of, and dams of earth and brushwood thrown across from bank to bank at different favorable points. When the water comes down, its level is thus raised against these bunds and it is skilfully directed down the secondary channels, natural or artificial, whose mouths are just above the dam, and which in their turn are bunded. By a similar

method, the water is turned down still smaller channels until finally it is thrown on the fields, which are bunded all round to retain it. When the bunds of the main stream are over-topped and carried away, which usually happens in a very short time, those lower down the stream get their share of water—and so skilful is the organization, that although these floods last but a very few hours, the water is distributed in the above manner by hundreds of weirs and minor channels over a large extent of cultivation—and with, generally speaking, remarkably few disputes.

199. The great defect of the system is that, if only a small quantity of water comes down, the bunds lower down the stream, go without; if a large quantity comes down, the violence of the torrent is so great, that the earthen bunds are carried away in succession too rapidly, and three-fourths of the quantity is wasted. Moreover the cultivation is precarious in the last degree as rain is so very rare. If masonry dams or weirs could be substituted for these earthen bunds, it is evident that the water would be under far better control than at present, and moreover could be stored up for future use in the bed of the nullah above the weirs. By a proper system scarcely any would be lost. Suppose, for example, a nullah some fifteen feet deep, with a fall in the bed of twenty feet per mile—it is evident that, if dams be constructed from bank to bank at every three-quarters of a mile, the surplus water passing over their tops in succession, a series of still water canals would be formed whence the water could be drawn by means of channels or the Persian wheel. If the beds of these nullahs were too shifting and shallow for this, then the waste water could be thrown by means of small side cuts into artificial earthen tanks. By a proper application of these two methods, there is little doubt that a great extent of country now lying barren could be brought under irrigation.

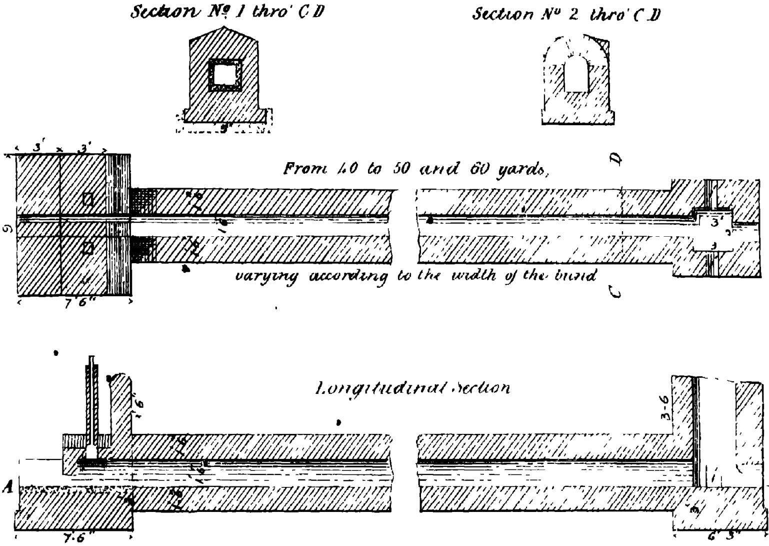
In the construction of such weirs, the same rules apply as have already been stated with regard to tank dams—wherever the banks are at all liable to be cut away, great precautions are necessary to prevent the weir being turned. The masonry must be carried well into the banks on both sides and water walls added for some distance both up and down-stream.

200. The following description is from Col. Baird Smith's work :—

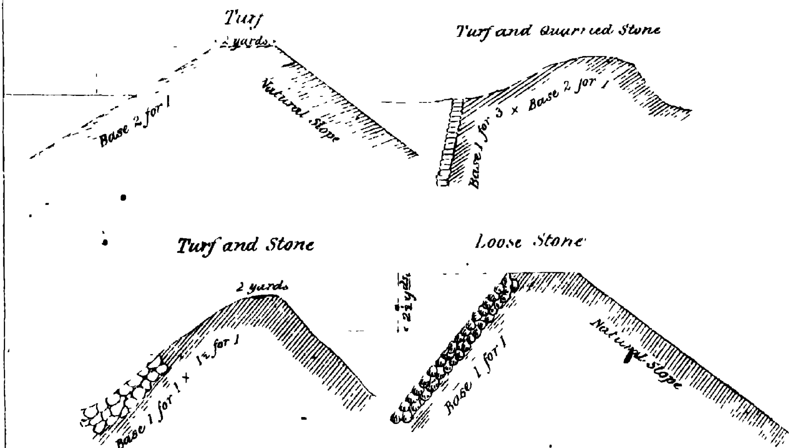
The tank which bears the rather formidable name of Chumbrumbaukum is one of

IRRIGATION TANKS

Plan of a Sluice for large Tanks



Sections of Tank Bunds



the finest in the Madras Presidency. It is picturesquely situated in the vicinity of bold hilly ground, and looks like a natural lake in a position where such a sheet of water might very readily be looked for. Beyond furnishing the water and the site, however, nature has had very little to do with its creation. It is purely artificial, and its supply is retained by an embankment 3 miles 5 furlongs 20 yards in length, ranging from 9 to no less than 28 feet in thickness, and from 16 to 26 feet in height. Its area is 9¼ square miles, and its volume may be estimated at 3,000 millions of cubic feet of water. It maintains a sheet of rice cultivation, nearly 10,000 acres in extent, yielding to Government an annual revenue of rather more than 50,000 rupees, and the cost of improving its various works, and keeping them in efficient repair has averaged, during the last 20 years, about 7 per cent. on the revenue derived from it. Its apparatus for distribution consists of 10 irrigation sluices. Its safety during floods is insured by the action of six waste weirs or calingulahs, giving in the aggregate a breadth of escape channel of 676 feet, with a depth below the crest of the embankment ranging from 6 to 13 feet according to position. Through this area an enormous mass of water can escape, and as the supply is dependent almost exclusively on natural rain-fall and merely local drainage, the protective provision has proved adequate, and breaches have been very rare.

201. The irrigation works in Ajmere and Mhairwara are not merely preventives against famine in years of drought, but are, as a rule, absolutely necessary to the production of crops. The undulating nature of the country causes the rain-fall to flow off the surface of the country very rapidly, and the beneficial effects of a heavy fall of rain last but a very short time. This evil again is aggravated by the spasmodic nature of the rainy seasons, the greater portion of the rain frequently falling within a short time, instead of being evenly distributed over the months during which wet weather may be expected.

The tanks are not intended for perennial irrigation, but were designed with a view to securing both the Khureef and Rubbee crops. This object they fulfil exceedingly well. The most important crops, raised by them are in the Khureef, Indian corn; and in the Rubbee, barely and gram. Wheat is grown to a small extent during the Rubbee, and the commoner crops, such as "bajra" and "jowar" are largely sown during the Khureef; small quantities of rice are also met with in the immediate rear of the embankments.

The Khureef is sown after the first fall of rain, and the whole of it generally receives a watering at the end of September, or the beginning of October, which brings it to maturity; if the season is unusually dry, it requires two waterings; the crop is then cut, and the ground, retaining the moisture from the last watering of the Khureef, is immediately ploughed up for barley or gram. The Rubbee crops receive two

or three waterings from the tank according to the quantity of water available; any deficiency being made up by irrigation from wells, which are quickly and cheaply made,—the water being kept close to the surface by percolation from the tank.

202. The success of the tanks from an agricultural point of view is undoubted, and the financial results, as shown by Colonel Dixon in pages 137 and 205 of his book, are equally satisfactory.

Districts.	Expenditure on tanks.	Increase of revenue due to tanks.
	RS.	RS
Mhairwara, ...	2,11,112	6,41,234
Ajmere, ...	3,76,451	3,17,771
Total Rs., ...	6,17,563	9,59,005
	Net gain, Rs., ...	3,41,442

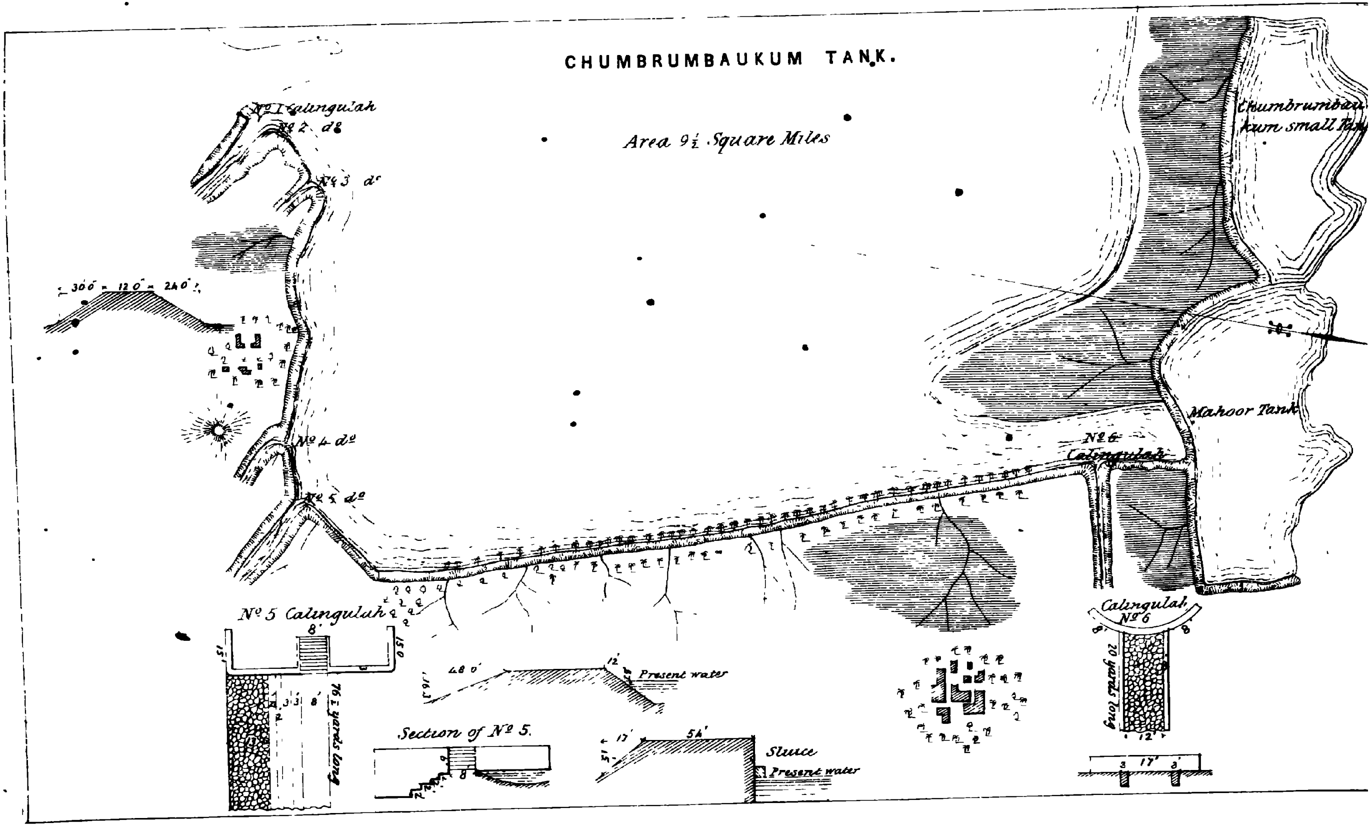
Of six tanks examined by Lieut. Home, R E., in 1868, all except one, are, after paying all expenses, giving a return for the money expended on their construction, and that the net income of the whole six is nearly 5 per cent. on the total capital.

This favorable result is undoubtedly due in part to the cheapness of original construction. The following are averages of the rates given by Colonel Dixon in his book:—

Description of work.	Rates.					
	Mhairwara.			Ajmere.		
	RS.	A.	P.	RS.	A.	P.
Masonry set in lime, per 100 cubic feet, ...	3	13	3	4	12	11
Do. do. mud, ditto, ...	2	6	3	2	7	0
Earthwork in embankment, per 1,000 cubic feet,	2	8	0	3	0	6

The rates now obtaining for masonry are double those above quoted, and the earthwork rates have also risen, though not in the same proportion.

CHUMBRUMBAUKUM TANK.



From the data afforded by these six tanks, it would appear that each acre requires 177,261 cubic feet to irrigate it; now, irrigation is only carried on from these tanks for about six months in the year, hence double that amount would at first seem to be required to irrigate one acre for a whole year. This, however, is not the case, for the irrigated land is nearly always double-cropped, as explained above, and consequently the volume above-mentioned would actually suffice to irrigate one acre for one year; that is to say, the land would require a total depth of 4·07 feet or water during the whole year, or one cubic foot of water per second from the tank would irrigate 178 acres in a year.

203. The following descriptions of some of these Irrigation tanks are from Col. Dixon's work:—

'*Kabra tank embankment.*—The Plate gives representations of the plan, section, and elevation of the work. AB shows the bund or embankment blocking up the gorge left open by Nature in the line of hills for the passage of the rain-water. Towards the water-line is the wall of masonry, having three bastions with two flights of steps leading down to the water. The wall of masonry is supported by an earthen embankment, the upper level portion of which represents the terreplein of the bund. D denotes the nuddee, or water-course, which has been closed up; whereby the water, collecting in one mass, constitutes the tank. The section through AB shows the thickness of the masonry and earth. The escape, C, has been cut through the hill. It has a wall of masonry towards the water-face perforated with apertures for sluices, through which the water is conducted to drains made of earth by the cultivators, leading to their several fields. The excess of water, after the filling of the tank, passes over the summit of the masonry wall, and flows off to fill weirs and tanks constructed to its rear. A second opening, or outfall, is made in the opposite hill, as is shown in the Survey Map.

The basin drained by the Kabra nuddee, at the place embanked, embraces an area of about seven square miles. During heavy rains, the stream swells to a mountain torrent. It was therefore a question of the first importance, that the work should be extremely substantial and capable of resisting the pressure of a wide expanse of water, having a depth of 20 feet. The length of the bund is 620 feet; the foundation has been sunk to the rock 9 feet in depth, having a breadth of 27 feet, built of stone with limestone mortar. The front wall slightly decreases in breadth as it rises in elevation, each course of masonry having a narrow ledge towards the water-face, as the breadth decreases; the weight of the superstructure is thus kept well within the perpendicular line. By gradual decrease, the masonry is reduced to 10 feet in breadth at the top. Its height from the foundation rock to the summit is 33 feet. The rear embankment, continued through the whole length of the bund, is 70 feet in breadth, its greatest elevation being 28 feet and 6 inches. The water in the tank, after rising within 4 feet of the upper line of masonry flows out by the outfalls on the right and left of the bund. Granular limestone is in such abundance, and so easily quarried, that it has been exclusively used as the building stone. It was

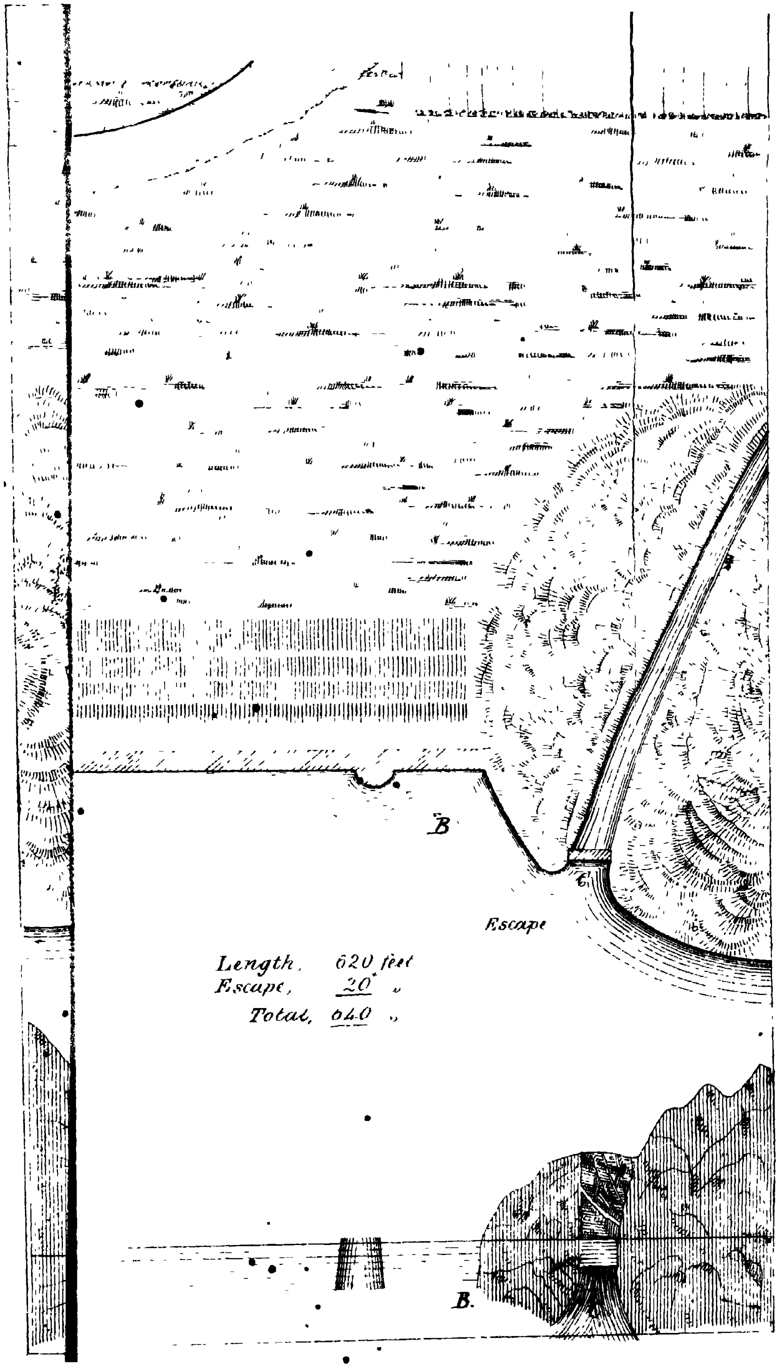
contracted for by the Zemindars at the rate of ten cubic yards per rupee, tools being provided at our own expense. The stone was then carted to the works at a stated contract price. The quarries being near to the bund, this charge was equally reasonable with the original cost for excavation. Earth for the embankment was provided from the bed of the tank, ramps of earth being thrown up for the convenience of the beldars and cattle, as the elevation of the bund increased. Latterly, as the soil immediately in front became exhausted, earth was taken from the rear. The embankment in immediate contact with the front wall of masonry was well beaten down and watered from time to time. The beldars were paid by contract. A low sloping bank was thrown up in front of the masonry, in view to ease off the pressure of the water; and to prevent the earth of the main embankment from being washed away by heavy rain, it has been provided with a dry stone retaining wall from 4 to 6 feet above the surface of the ground. The masonry and the embankment were carried on at the same time; the presence of the earthen bund obviated the necessity for scaffolding, while the earth was well trodden down by coming in constant contact with the feet of the work-people. The work was commenced in 1837, and was completed in two years. Many facilities were offered in its construction. Stone, lime, and wood were in ample abundance and near to the scene of work. Water was the grand difficulty to be overcome during the first season. It was arranged for, by sinking several wells in the rocky bed of the nuddee.

The expense of the work was as follows:—

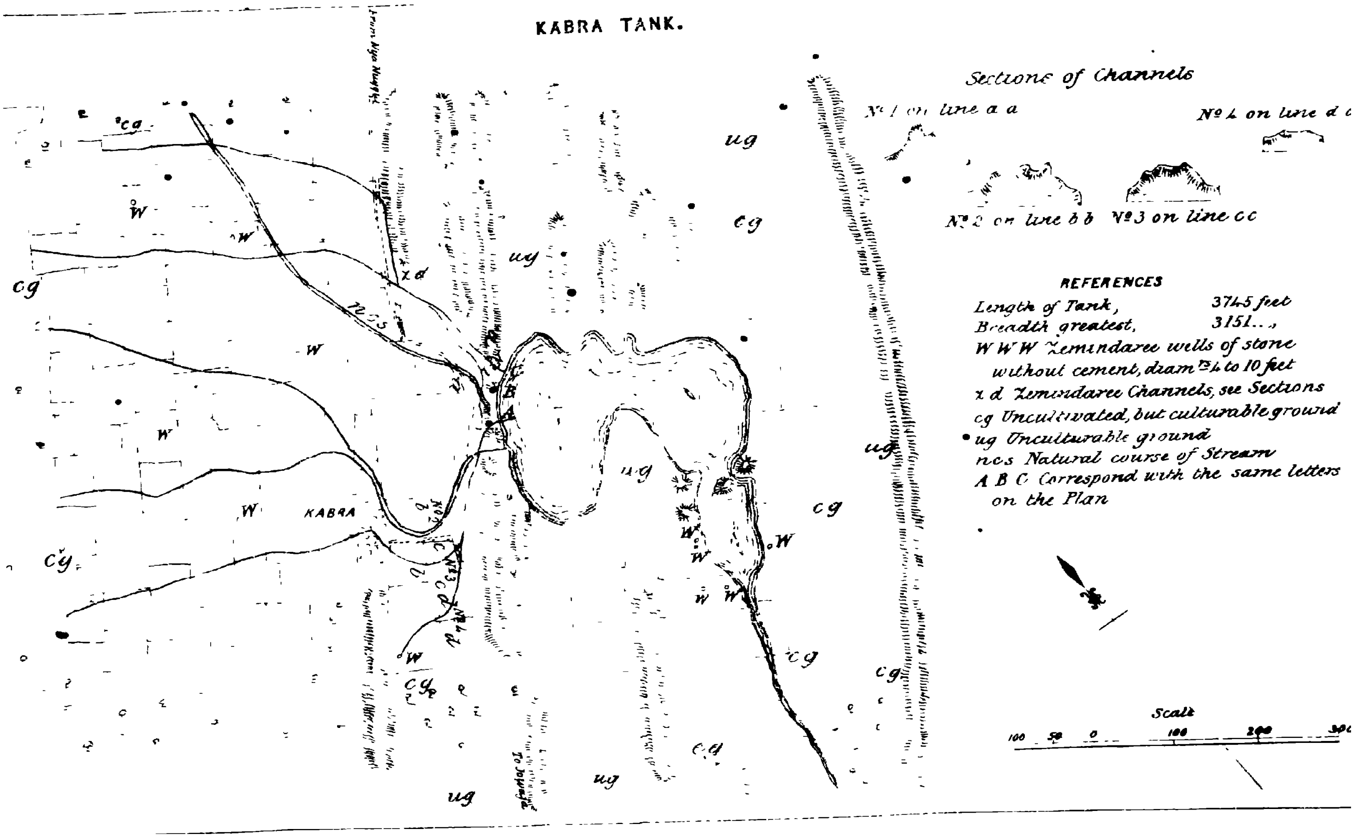
		RS.	A.	P.
153,121 cubic feet of lime masonry,	-	4,365	6	0
8,830 „ dry stone masonry,	-	121	12	6
725,215 „ earth well beaten down,	-	1,758	1	2
Total expense of the Kabra embankment,	-	6,245	3	8

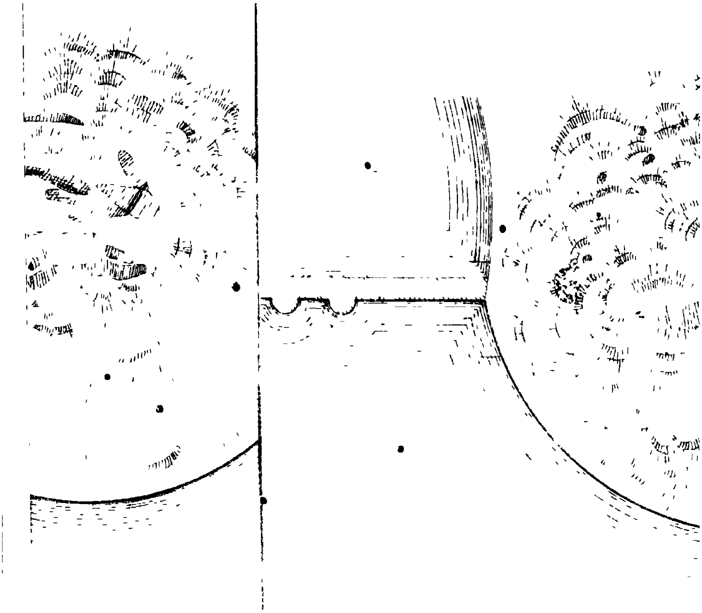
Area of tank = 7,938,000 square feet.
Cubical contents = 57,693,384 cubic feet.

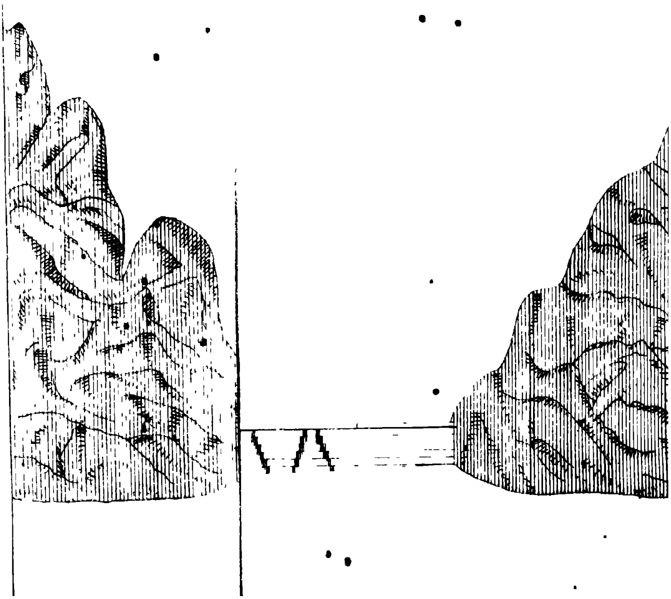
204. *Roopana Weir.*—The Roopana Weir is thrown across a hollow or gorge in a low range of hills, closing the water-course which drains a wide area of country. The foundation rests on solid rock, the breadth of the masonry being 10 feet 6 inches at the base, and gradually decreasing, through an elevation of 18 feet, to 3 feet 3 inches at the summit. The ground to the south-west of the nuddee is secured by a wall of masonry, 6 feet at the base and 4 feet at the summit, having an embankment of earth to its rear, 30 feet in breadth and 11 high. The weir, over which alone the water passes, with the single embankment to the south-west, measures a length of 522 feet. Small bastions have been built in the weir masonry to give stability to the fabric. The water from the weir, after winding its course round the ends of several small ranges of the hills, goes to give productiveness to other villages to the west. The influx of water is so great that the chudur, or cascade, overflows nearly the whole year. Land suited for cultivation is the only desideratum. It is restricted to that confined between the several lines of hills, all of which had to be reclaimed from dense jungle before the plough could be called into action. This work was constructed in 1846 and 1847, at a cost as below stated:—



B
C
Escape
Length, 620 feet
Escape, 20 "
Total, 640 "
B.


KABRA TANK.
Sections of Channels
No 1 on line a a
No 2 on line b b
No 3 on line c c
No 4 on line d d
REFERENCES
Length of Tank, 3745 feet
Breadth greatest, 3151 ,,
W W W Zemindaree wells of stone without cement, diamr 4 to 10 feet
x d Zemindaree Channels, see Sections
cg Uncultivated, but culturable ground
ug Unculturable ground
n c s Natural course of Stream
A B C Correspond with the same letters on the Plan
Scale
100 50 0 100 200
From Nya Nuggur
To Jowaja
KABRA
ug
cg
W
x d
n c s
No 2
No 3
No 4
A
B
C





	RS.	A.	P.
43,680 cubic feet of lime masonry, - - -	2,095	8	10
73,850 „ earth, - - - - -	110	4	0
Total expense of Roopana Weir, - -	2,205	12	10

205. The following extract, from the same author, describes the kind of work referred to above, as being applicable to the hill streams of the Punjab:—

Much has been said of the usefulness of small weirs thrown across nuddees, as an auxiliary to irrigation. The plate represents two of such weirs. No. 1 is thrown across the Kabra nuddee, which passes near to Nya Nuggur. It is 315 feet in length forming a straight line, and stretching across the bed of the stream Advantage has been taken of rocks which crop out of the nuddee; serving for a firm foundation, and, in some measure, as a rear support to the masonry. The section on *x*, *x* gives a profile of the weir, having a breadth at the base of 10 feet, and of 6 feet 10 inches at the top; the height rising to 13 feet. The work is strengthened by small bastions to the front. The water maintained in the nuddee by this weir extends to the distance of three quarters of a mile, supplying wells on both sides of the nuddee, and indirectly proving useful by the filtration of water through the soil.

No. 2 is another specimen. Its length is 145 feet. Half of the masonry rests on a firm rock. For the other half, no hard foundation was attained. The influx of the water after digging 6 feet below the bed of the nuddee was so great, that all efforts to remove it proved unavailing. The trench was filled up with unslaked lime, and stones promiscuously thrown in, until the water-level was attained, when the masonry was built with stone and mortar in the ordinary way. This work has stood ten years, and is as firm and stable as the day it was raised. The sections on *y y* and *z z*, show the thickness of the masonry. The elevation affords a front view of the weir from its bed, on the nuddee being dry.

In works of this kind, over which the mountain torrents during the rains pass several feet in depth, attention should be directed to the security of the flanks. The masonry at each end of the water-way should be elevated a few feet above high-water mark, and firmly embedded in the banks. With these precautions, the torrent may roar in its passage over the weir without exciting apprehension.

206. The following is a description of the Sholapore Tank, a large work lately constructed in the Bombay Presidency.

The site of this lake is situated generally about 10 miles north of Sholapore, the village of Ekrookh being about the centre.

The total length of the *Dam* will be 7,200 feet; the masonry portions on the northern and southern ends being respectively, 1,400 and 1,330 feet. The maximum height of the earthwork over the centre of the stream (the Adeela) will be 72 feet, or 7 feet above highest flood-line. The slopes provided for are 3 to 1 on the waterside, and 2 to 1 on the outside face of the bund. The water slope of dam below flood-line is to be pitched with stones 2 feet in length. The top of the masonry dam to be 3 feet above highest flood-line, and the dam to be surmounted by a parapet wall 3 feet

high. The earthwork on the outside face to have a slope of 2 to 1 and that on the inside 3 to 1. This face is to be pitched.

The area of the tank at the level of the water weir will be 175,000,000 square feet, or $6\frac{1}{4}$ square miles. This is $\frac{1}{22}$ of area of the rain-fall (141 square miles), and as the tank is calculated to hold 2,222,145,000 cubic feet of water, it will be filled by a rain fall of $6\frac{1}{2}$ inches on the whole drainage area.* The maximum depth of water, when the tank is filled up to be waste weir level, will be 60 feet.

207. The *Waste Weir* will be constructed on the northern end of the bund, and will consist of a channel 250 feet in width, which will be carried through the spur and will lead the waste water direct to a large nullah, by which it will rejoin the original stream, about a mile below the line of bund. The depth of cutting on the ridge of spur will be 10 feet, at which level the material for the sill of the weir will be sufficiently hard to resist the wear of running water. It is also proposed, however, in order to preserve the level of the weir crest, to lay down a flooring of masonry 25 feet wide, with an average depth of 1·5 feet across the waste weir.

The maximum discharge of the river Adeela, which is the stream on which the Sholapore lake is situated, is about 37,000 feet per second, according to the flood line shown by the villagers, and calculated by the usual formula ; but there is reason to doubt whether it ever really reaches that amount ; however, as this flood only lasts for a very few hours, it is not that one by which to decide the dimension of the waste weir. The discharge of that flood which continues for four or five days is about 11,000 cubic feet per second. The velocity of discharge on the crest of the waste weir will be a little over 10 feet per second, but supposing it to be only 10 feet per second, with a width of 250 feet and depth of 5 feet—which is the maximum depth provided for—the discharge is 12,500 cubic feet per second ; however, as the water will have been escaping all the while, the flood line will not rise to the height of 5 feet except under a very continuous rain-fall of above a week's duration at a time, and this is very improbable in these eastern districts.

208. It was originally proposed that all the *Regulating Sluices* for discharging the water from this lake should consist of iron pipes laid in masonry, with screw corks fitted on to their lower extremity, but as this design was considered hardly sufficient or safe for the sluice of the perennial canal, the idea of the tower and tunnel as originally proposed by Sir Arthur Cotton was adopted ; the method of working the small valves in the tower is shown on the tracing. The sluices of the two high level canals will, however, consist of the former design.

The joints of the piping, though generally made with iron filings or melted lead, should in this case consist of flanges bolted together with bolts and nuts, as no risk should be run. The foundations of all the sluices will be on rock or hard moorum.

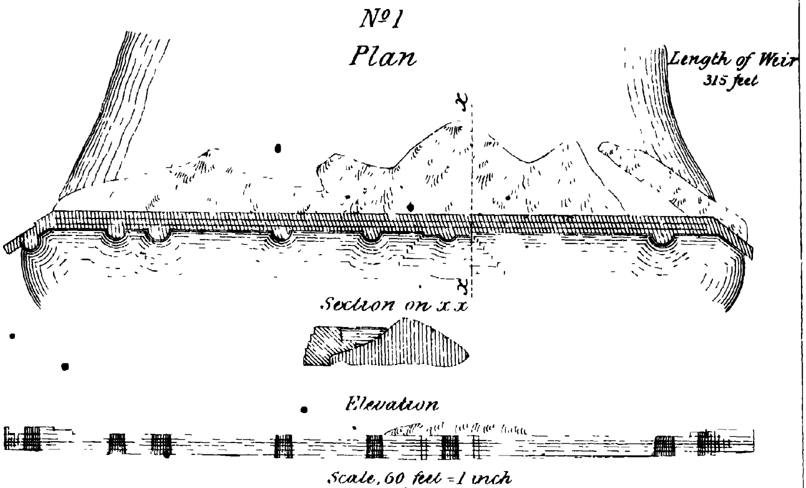
209. It is proposed to run three lines of *Canals* for distributing the water ; that on the lowest level will be the perennial canal, the length being 28 miles. Although, the level of this canal at the head is 20 feet above the bed of the nullah or bottom of the lake, the quantity of water lost is only about 1-110th of the whole contents of the tank. This is not considered so valuable as the greater command of country which will be attained by the high level.

The next will be a four-months' canal. It will start from the opposite side of the

* Supposing the whole ran off ; or by a rain-fall of 9 inches, supposing two-thirds ran off. The minimum fall at Sholapore is 13 inches.

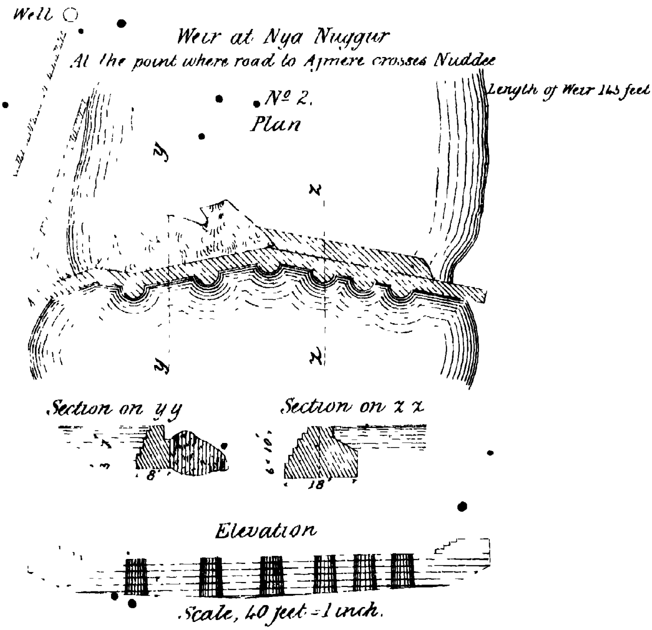
WEIR AT NYA NUGGUR.

At the point where road to Marwar crosses Nuddee.

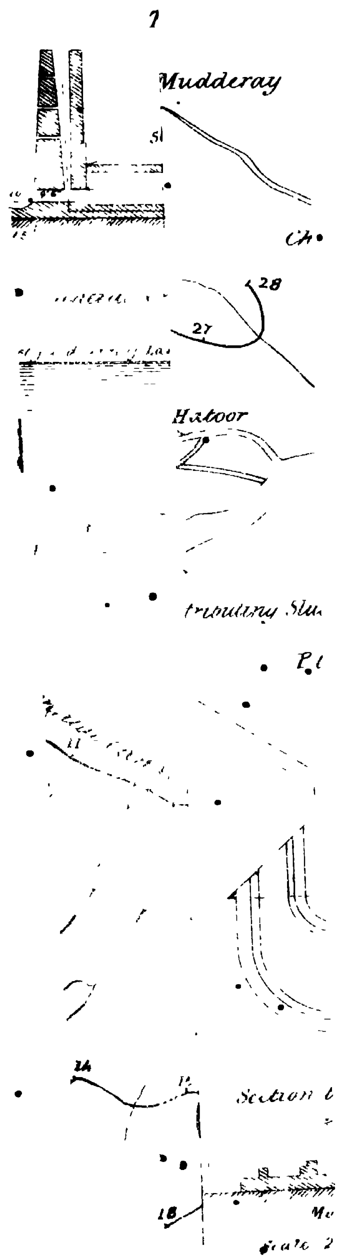


Weir at Nya Nuggur

At the point where road to Ajmere crosses Nuddee



E TANK.



valley, cross the waste water channel, and terminate after a length of 18 miles. The third line will be on the same side of the valley as the perennial canal, but at a level 25 feet higher. It will also be a four-months' canal, and has only a length of 4 miles. The area of land commanded by these canals respectively is as follows :—

Left bank, perennial canal.—Discharge = 44 feet per second. Area 25 square miles, or 16,000 acres.

Right bank, four-months' canal.—Discharge = 42 feet per second. Area 21 square miles, or 13,440 acres.

Left bank, four-months' canal.—Discharge = 21 feet per second. Area 10 square miles, or 6,400 acres.

The following calculations give the quantity of water required by the canals between the ends of one monsoon and commencement of next eight months :—

912,384,000 cubic feet, quantity run off by perennial canal in eight months.
435,456,000 ditto, right bank canal in four months.
217,728,000 ditto, left bank canal in four months.
753,000,000 ditto, evaporation in eight months, 7 feet in depth.
20,000,000 ditto, lost in bottom of tank.

As the tank will fill with less than the minimum rain-fall, the quantity of water withdrawn by the four-months' channel will be compensated for during the monsoon ; and as the capacity of the tank is 2,222,145,000, there will be a considerable surplus, since the quantity required for the perennial canal, evaporation and loss at bottom of tank, is only 1,682,380,000. The average velocity attained with the present distribution of fall in the canal is about 21 or 22 inches per second.

Estimated cost, Rs. 7,76,000.

CHAPTER XII.

RIVER INUNDATIONS—RIVER IMPROVEMENTS.

210. Before dismissing the subject of Irrigation Works, it may be useful to say something on River Inundations and River Improvements, with both of which the Indian Engineer has often to deal.

Inundations.—The tendency of Indian rivers to shift their course and raise their beds by the deposit of silt has already been remarked upon—one effect of this tendency is to cause severe inundations during the rainy season. Nearly all the rivers of the Punjab and Upper India in general, flood their banks for a certain breadth on each side throughout a considerable portion of their course, these inundations gradually increasing as the river approaches the sea, where it terminates in an immense delta—which, during the rains, is little better than a vast swamp.

Now so long as these partial inundations are confined within reasonable limits, little harm and much good result from them. They do not, it is true, tend to the healthiness of a district, and they prevent any autumn crop being sown on the inundated land—but the silt deposited by the water tends so to fertilize the land that on the subsidence of the inundation in the cold weather, the richest crops are produced with scarcely any trouble. In such parts of the country, it is customary for the cultivators to construct temporary villages which are abandoned when the *rubbee* or spring crop has been reaped—or such villages as are permanently inhabited are built upon natural or artificial mounds, and if necessary, defended by embankments.

The autumn crops which lie along the edge of the inundation are also defended by bunds which often extend for miles in length; these bunds are of no great height or solidity, as they are not built where the water is deep and are merely meant to save the crops.

211. But such inundations, from local causes, often attain to great

force, and sweeping over the low ground, may extend through the heart of a district with a breadth of many miles and a depth of several feet. Houses, villages and crops are swept away—cattle and even human beings destroyed. Moreover, the water no longer flowing with a gentle and scarcely perceptible current, acquires great velocity in its course through the low land, and having no time to deposit its silt, improverishes instead of nourishing the soil. An Engineer is often called upon to provide a remedy for such a state of things, and there is no work that demands more patience and skill, and none more anxious or interesting in its results.

Thus it will be seen there may be two classes of embankments designed to provide for two different states of things, viz., (1), long continuous lines of embankments to check the spread of lateral inundations, and confine the river within certain limits; or (2), a comparatively short piece of embankment thrown up to shut out a merely local inundation.

212. 1. The science of Embanking, if it may be so called, is still in its infancy, and very diverse are the opinions of Engineers on the subject. It is contended by the opponents of river embanking in general, that such embankments by restricting the bed of the river within certain bounds, cause such a rapid elevation of the bed from the free deposit of silt, that the waters of the river are year by year raised to a much higher level; the embankments have therefore to be raised and strengthened regularly, so that at last the bed of the river may be raised considerably above the level of the surrounding country, as is the case with the Po in Italy, and the Mississippi at New Orleans—thus, whenever a breach may occur, the inundation is infinitely more destructive than any number of inundations when the river is allowed to take its own course unchecked.

On the other hand it is contended, that by confining the river between embankments, the velocity of the current is increased and thus the amount of silt deposited is lessened—that the improvement of the river thus effected for navigable purposes, together with the great area of land annually saved from inundation, more than compensate for the loss caused by an occasional breach of the embankment,—that the evils of the present system of embanking arise from the want of method by which it has been characterized, and by no means involve the general principle,—and that if a certain amount of space be given for the river

to expand in on both sides of the cold weather channel, there is nothing to be feared with ordinary precautions.

The general question had to be dealt with practically in this country in the case of the Damooda river, as connected with the alignment of the East Indian Railway. The opinions of different Engineers and of the Committee appointed by Lord Dalhousie to determine the necessary measures, will be found in the Bengal Government Selections.

In America, the question of embanking or non-embanking has been practically settled by the occupiers of the land on both sides of the Mississippi, where, as fast as the ground has been taken up and cleared, bunds or *levées* (as they are there termed), have been thrown up as a defence against the encroachments of the river. The maintenance of these levées is being gradually brought under the control of the States in which they are situated, and Civil Engineers are now generally employed to lay them out, and construct them on the best principles.*

213. 2. Whatever opinion may be formed as to the expediency, or otherwise, of long continuous lines of embankments, it is still clearly necessary to resort to embanking for defending a country from local inundations, and it is to such, therefore, in especial that the following remarks will refer.

The first point to be ascertained is the actual locality of inundation at its exit from the river, as this will tolerably define the length of the embankment that will have to be constructed. At the same time, the *cause* must be sought for, and this will generally be found to be—a *set* of the river towards that particular spot where the inundation breaks out, with perhaps the existence of a valley or old water-course or ancient bed of the river into which the inundating water flows, and by which it is carried into the interior of the country. It is in general impossible to ascertain the cause of this set, or at least very difficult. For the cause may exist higher up or lower down, or near the place itself, and these rivers are so capricious in their meanderings, that we know little of the laws affecting their various changes of course.

In some cases, however, the cause *may* be ascertained and attempts may be made to divert the set of the stream towards the opposite shore. The means to be adopted with this end in view will be discussed further

* The student may consult Hewson on "Levées" and Ellett "On the Mississippi and Ohio Rivers;" also the very able report which has already been referred to, "On the Physics and Hydraulics of the Mississippi River."

on under the head of "Improvement of Rivers." Such experiments are always doubtful, and usually require to be carried on through a series of seasons to be successful. It is, in fact, battling with a giant and requires great perseverance, energy and skill to obtain any success. Works constructed when the river is low, are often swept away by the first freshet —and the work has to be done all over again. If therefore the damage done by an Inundation be great, but especially if it has a tendency to increase, the difficulty should be at once boldly met, and embanking be resorted to as the only efficient remedy.

214. The locality of the exit of the Inundation being ascertained, the extreme limits must be found out, that is, the *breadth* of the invading body of water; and its greatest depth should be ascertained at as many fixed places as possible; this will be determined by actual observation during the flood, in a boat or otherwise, and by inspecting the flood marks left on houses, trees, &c., as soon after the waters have receded as possible.

The fall of the ground from the points where the flood depths have been ascertained near the river bank, along the course of the inundation inland, should then be determined by levelling, and this being all plotted down on a plan of the surrounding country, the line of embankment will be determined from the following considerations:—

1st. It is evident that the two ends of the Bund should rest upon high ground not liable to be inundated, or that at any rate the upper end must so rest, or there will be the great danger of the embankment being turned and flooded in the rear.

2nd. If the river, as is generally the case, is cutting away its bank, the bund must be fixed at some distance inland, or the river may eat its way to the foot.

3rd. All canals and water-courses (unless it is intended to shut them up) will require Masonry Works over them, where crossed by the Bund, so that a proper quantity of water may still be allowed to pass for the purposes of Irrigation—wherefore it is desirable to cross as few of these as possible, and they should be crossed at right angles.

4th. It is evident that the water when stopped in its onward progress by an embankment, will rise to a much greater height than it did when flowing on unchecked. The greatest height to which it can rise at any point of the bund, will be found by finding the fall from the

opposite point on the river bank, and then adding to this fall the height of the highest flood mark, observed at the point on the bank. Thus, if the water rises two feet high when overflowing its bank, and the fall from the bank to the opposite point at the bund be four feet—then the water may rise to a height of six feet when checked by the bund. I say, *may* rise, for this will only happen when the water has no free outlet at the lower end of the bund, or when the fall down the course of the inundation is greater than the fall down the bank of the river. Nevertheless, this horizontal line of still water (as it may be called) should always be taken to determine the height of the bund, three feet being allowed in height over and above this total for safety's sake. As many points, therefore, on the river bank whose flood marks are clearly determined, will give the required height of the bund at as many opposite points in the proposed line of the bund. It is evident then that the more inland the bund is made, the greater will have to be its height, and in all probability, the greater its length.

215. These four conditions will generally determine the line of embankment, which to satisfy them should, (1) have its two ends well secured, (2) not be too near the bank or it may be cut away, (3) should cross as few water-courses as possible, and those at right angles, (4) should not be too far inland or it will have to be made very long and of a great height.

There are also minor points which may have to be considered, such as the taking up of cultivated land, the defending any particular village, avoiding bad soil, &c. The land between the bund and the river will be greatly enriched from the deposit of silt. On the other hand, such portions of any canals as lie between the bund and their mouths on the river bank, will be much silted up, and require heavy clearing after the water has retired.

The height of the bund at various points being determined upon, the line should be cleared and levelled, and then the required height at any number of intermediate points may be ascertained by levelling.

216. The section required for either class of embankment will depend on the depth of water and its velocity. I suppose earth to be the material employed, as stone would be rarely procurable, and generally much too expensive.

Unfortunately we have few rules to determine the necessary thickness of material to resist water in motion. We can calculate the mere dead

pressure from the depth and area of the surface pressed, but the two great practical dangers to be guarded against come under no fixed rule. These are, 1st, The tendency of the water to cut against the slope of the bund, either from the velocity of the stream or when agitated by waves; 2nd, The soaking of the water through the mass of new earth, which, unless speedily checked, will cause breaches in many places. It is evident that both of these dangers diminish in proportion as the bund gets older and the earthwork has time to consolidate—it is during the first year that the greatest danger occurs. There is also a third source of danger which should not pass unnoticed, and that is the holes made in the embankment by rats or other vermin.

The thickness of the bund at top will depend on whether it is also to be made use of as a public road or not. The traffic on it tends to consolidate the earth, but it is also apt to break it down, and lower the crest. A top width of 6 to 10 feet will generally be sufficient, with a rear slope of 1 or $1\frac{1}{2}$ to 1, according to the nature of the soil. On the water side, the slope cannot be too long for safety, and the degree of its flatness is a mere question of expense. It ought never to be less than 3 to 1, and, in general, should not be less than 5 or 10 to 1.

217. The earth should be thrown up in layers and well rammed, and the surface soil loosened to make the new earth bind better with the old. Sand may be allowed for the heart of the bund, but not for the two slopes. Stiff clay is apt to crack, and is not so good as light clay or good alluvial soil. Shrinkage should be allowed for, as in the case of Road Embankments. The amount depends on the nature of the soil and usually varies from $\frac{1}{5}$th to $\frac{1}{10}$th the original bulk.

The earth for the construction of a bund should on no account be taken immediately from its front, the effect of which would be either to deepen the pressure of the water against it, or to make a dangerous stream along its face. No excavations should be allowed within 20 feet of the toe of either front or rear slope.

218. When the foundation soil is very boggy, it may be necessary to seek for an artificial foundation to support the bund. American writers recommend brushwood, as in the case of a road bank, but the danger of leakage is very great, and may result in the new bank being undermined and swept away. If draining is too expensive, the sub-soil may be consolidated by wooden piles made of any common wood, and

driven in 4 or 5 feet deep, or the earth may be excavated for 3 or 4 feet, and the excavation filled in with sand. A simpler and cheaper remedy is to use *sand-piles, i. e.*, a wooden pile of about one foot diameter is driven in some feet, and then withdrawn, the hole so made being filled in with rammed sand, and this is repeated at intervals of 3 feet or so in each direction over the whole of the boggy surface.

219. If possible, the water-slope should be artificially protected. The best plan is to turf it, or at least the lower half of it; but unless grass and water are plentiful and close at hand, the expense would be too great. Grass roots may be dibbled in here and there, or grass seed sown and well watered. If none of these can be managed, then loose brushwood may perhaps be available, or coarse mats and *chuppahs*. In Holland, straw is used for the same purpose, twisted into ropes about 2 inches in diameter; it is laid on the face of the bank and pinned down with forked sticks, rope after rope being added till the whole is covered.

220. Any dry streams or water-courses crossed by the bund should be carefully filled up for a certain distance in front, as when the inundation first breaks out, these nullahs are filled with water, which will often run down their course and cut clean through the bund, even before the water has attained any height. Wherever such nullahs appear either at right angles to, or oblique with, the bund, it is advisable to throw out *spurs* of brushwood and piles nearly perpendicular to the stream of water to divert the set of these streams from the bund. These spurs may be made of a double row of piles of jungle wood, about 4 feet apart and filled in with brushwood—they should be higher than the water, and may be necessary in considerable numbers, as in the defence of a river bank.

In crossing canals, Regulators will be required, made after the ordinary manner of regulating bridges, the roadways being level with, and connecting, the top of the bund.

221. In a new embankment, the greatest watchfulness is necessary when the water comes up, to prevent breaches. Gangs of workmen should be stationed all along, well supplied with mats, piles, mallets, &c. As soon as the water is observed to be soaking through at any place, mats or brushwood should be put in front to stop it, and if a regular leak occurs underneath, the bund must be well cut into and the leak dis-

covered and stopped. If the slope is being cut away, piles and brushwood must be applied to remedy it, and a spur thrown out to divert the set of the water. If a break occurs and the water rushes through with any force, as is generally the case, it will be almost impossible to stop it—the only thing to be done is to defend the sides of the breach with piles and brushwood to prevent it increasing, and to wait the first falling of the water to repair it. Breaches however, may be occasionally stopped with tripods made of piles placed in a row,—and stout chuppahs in front. Sacks of earth in sufficient numbers thrown into the breach are also useful, or old boats may be sunk.

Sluices of masonry are often fitted to bunds to irrigate the lands to the rear. It is better, however, not to fix them until the earthwork has proved itself firm.

222. *Improvement of Rivers.*—In forming plans for the Improvement of Rivers, the following are the objects generally to be kept in view:—1st, To protect the banks from the action of the current; 2nd, To prevent inundations of the surrounding country; 3rd, The removal of bars, elbows, and other natural obstructions to navigation; 4th, To maintain a suitable depth of water for boats, for the trade of the river.

1. To protect the banks, either artificial means must be resorted to, to divert the action of the current along the shore, or the banks themselves must be artificially protected. The latter plan can only be used when the banks are high, and not liable to inundation and the soil of not too loose a texture. If they are perpendicular, they should be cut down to a gentle slope, and defended by a revetment of turf, stone, &c., by sowing grass seed, or by planting low jungle or aquatic plants.

In Flanders and Holland, when a bank is to be protected, if the erosion take place *above* the ordinary water line, and the natural slope of the ground below is such as to support the weight of the bank, fascines are laid in horizontal courses and bound together by stakes running into the bank. When the bank is eroded *below* the ordinary water line, the course adopted is to form a species of raft of gabions strongly tied together and fixed into the banks by stakes, with their ends projecting into the stream. Other gabions are placed on these in a direction parallel to the bank, and fascines alternately crossing one another in the body of the raft, are laid upon this grating. The whole structure is firmly bound together and sunk by being loaded with stones

or bags of earth. Large hollows in the bank are filled with panniers loaded with gravel.

223. It is evident that the expense of the above methods must preclude their adoption for any great length of shore in general. The set of the water against a bank can however often be altered by constructing Fixed or Floating *Spurs* running out from the shore, which deflect the current to the opposite side.

These spurs generally consist of two or three rows of piles, the interval being filled with brushwood, which stand well against the stream, and by checking it and causing a deposit of silt, gradually effect their purpose. It is calculated that such a spur will defend seven times its own perpendicular length from the shore, viz., four times its length below and three times above. For economy of construction, therefore, the more perpendicular such spurs are run out from the bank the better, but as the force of the water is often so great, that if placed perpendicularly to the thread of the stream, they would never be able to stand, and as the effects of the back-water at the root of the spur are also very great, I have found that an inclination of about 45° should, in general, be given to them. A system of spurs should be so arranged, that the next one is put where the first one ceases to act, and the tops should in all cases be well above the surface of the water, so that the surface velocity may be checked as well as the under current. If the object is merely to protect the shore, it is better to use a greater number of short spurs than smaller number of long ones where the breadth of the current is considerable: it is evidently useless to run the spur into the slack water beyond the current. If the object, however, is to deflect the current to a considerable distance from the shore, so as to alter the *set* of the river, then long spurs must be used.

224. The following is a description of the brushwood spurs constructed between 1855-58, to defend the Cuttack Revetment Wall from the action of the Mahanuddee river.—

In 1856 a brushwood spur was constructed, the result of which was two-fold. Further silting up of the hollows under the revetment wall took place, and the line of deep channel of the river was diverted from a course dead on the revetment wall to a very favorable one, parallel to it. The spur consisted of a double row of piles driven 3 feet apart from centre to centre, and a width of 3 feet between the rows. These piles averaged 15 feet long and 8 inches in diameter at the head. They were driven 7 feet into the sandy bed, and according as a length of two or three hundred feet was

completed, the space between the rows filled up for a height of 6 feet, with fascines of brushwood, firmly packed and trodden down. The top was then tightly bound down by coir ropes, crossed from pile to pile, and the whole was thus rendered very firm and secure. There was no attempt made to weigh down the fascines with stones, as it would have been too expensive, and the result proves that this was not required, for, when the water rose over the spur, none of the brushwood bundles showed any inclination to rise, float away, or resist being confined within the original space allotted to them.

In 1858 a second brushwood spur was constructed by Mr. Armstrong, C.E. It was 1,923 feet long, and constructed similar to the one in 1856. This spur cost 5 annas per foot run; the one of 1856 cost 8 annas per foot; the difference is owing in part to the fact that the last built spur was erected during the dry weather, while that of 1856 was constructed in water. The great saving, however, was effected in the pile driving. The engine formerly used could only drive 24 piles per diem, with 16 men; the light ringing engine used for the second spur required only 12 men and drove on an average 50 piles. To assist the action of this spur, brushwood dams were run across the deep pools in the river, at various distances, from 100 to 200 feet apart, according to the depth of the water or the state of the revetment's foundation. These dams were formed of three or four fascines, in the centre were placed one or two stones, according to their size, and the fascines tied firmly round them with three coir ropes, one at each end and one in the middle; these bundles were about 5 feet long and 2 feet in diameter in the centre, and at the end 12 inches or so. These works were quite successful in their object.

225. On the Damooda river, in Bengal, the spurs used to protect the banks from the action of floods are constructed as follows:—

At an angle of 30° to general alignment of the bank, sál piles are driven 10 to 12 feet into bed of river, 5 feet apart; and in a double row, also 5 feet apart. These piles are connected by sál ties across, nailed by large 6-inch spikes, and are connected longitudinally by strong bamboos, as ties, in three places; 20 feet of this piling should be 1 foot higher than highest flood, and the piling should be carried inland some 20 feet. In continuation of the spur, a small earth bund should be carried back till it reaches ground higher than the flood, or to some 100 feet inland. The object of this is to prevent the water, when it rises, from flowing over the crest into the corner made by bank and spur; as, up-stream, the water is headed up a couple of feet, and advancing at a velocity of from 4 to 6 miles an hour, it pours violently into this hollow and gradually cuts the bank away. This action proceeds till the earth is cut away from the neck. A little protection, say one brick flat would be judicious in this corner. The tops of the remaining piles slope gradually down to the end, where they are 3 feet above the bed. At every 10 feet, a strut down-stream is required.

Intermediate to the sál piles, bamboos (from 20 to 24) are driven, also 10 feet deep; these are best put in by fives or sixes—being kept upright by the longitudinal ties. When this net-work is complete, 3 feet of stone or brick ballast are thrown inside—the top, about the summer level of river—the bed being excavated if necessary. On the up-stream side, a base of 10½ feet should be given; down-stream, 3 feet base will suffice.

In this net-work, fascines or bundles of brushwood (of sál twigs for preference) tightly compressed, measuring from 5 to 10 feet in length and 9 inches in thickness, are packed and forced down—cross bamboos laid over will hold these. However much this filling is forced down, it will always be found that a great deal of water will pass through.

Groins, 15 feet long, at right angles to the up-stream face, of spurs made of a single row of sál piles and bamboos, and protected by a stone or brick base at every 100 feet, will stop the scour along the face of the spur.

After the first flood, it will generally be found necessary to pack in two more layers of brushwood.

This brushwood spur is rather expensive, costing on the Damooda, not less than Rs. 9 per foot complete; it is, however strong and can be quickly made, provided the water be not deeper than 4 feet. It acts well, and is said to protect the bank for a length of six times the perpendicular, where another spur should be introduced if further protection be necessary; but this would only be the case in favorable positions, such as a straight part of the river, with a section rather over the average.

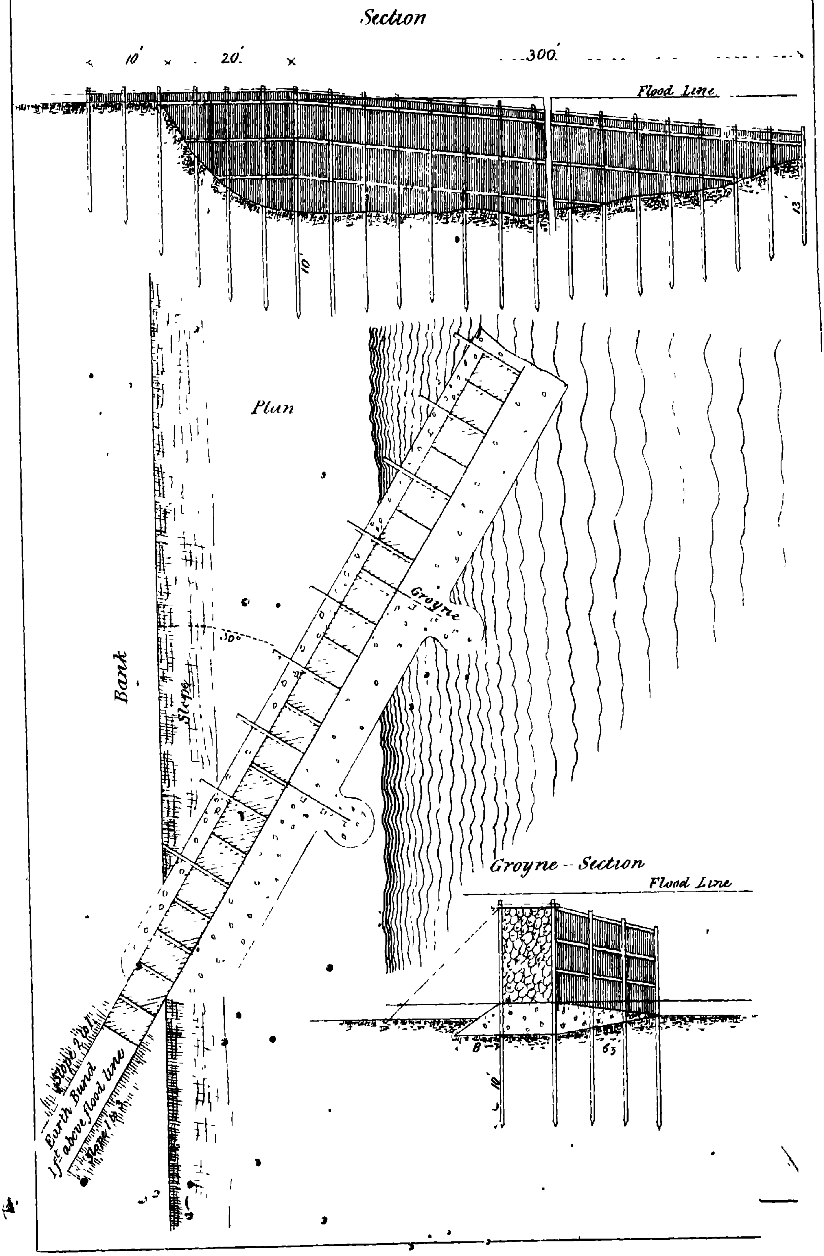
These spurs last a second season with repair; to trust them for a third would be very hazardous.

If they have acted efficiently, they should, in a couple of floods, have caused silt to deposit up to their full height.

226. On the Markunda river in the Punjab, and elsewhere, where the cost of deep piling would be excessive, a defence has been formed by large branches of trees tied to iron chains which are anchored at intervals apart by means of the ordinary well foundations.

These anchor wells were 300 feet apart, 7 feet diameter and 20 feet deep below bed at site. In the deep channel an additional well was sunk, to resist the greater force of the current at that place. The well masonry is 1½ feet thick; the inside being filled throughout with concrete in which five iron-bars of 1 inch diameter are inserted. These bars are fastened together below; two pass up the centre of the well, and three

SPURS ON THE DAMOODA RIVER.



at equal intervals between the masonry and concrete. They are again brought together at top and pass through double rings, through which the chain passes, and where it is permanently fixed by means of an iron clamp inserted between the rings.

The chain (of $\frac{3}{4}$-inch link) was stretched moderately tight, just sufficient to prevent its being lost by sinking in the quick-sand during floods. The trees were tied on with galvanized iron-wire, about 10 feet to each; they covered an average length of 3 feet of chain, exclusive of small trees and branches which were interwoven wherever the trees were thin.

227. The following is a Memorandum on Tree Spurs, on a similar plan to the above, which were constructed on the River Ravee, at Lahore, in the year 1865.

A place on the right bank marked A [*Plate* XXXIV.], (where the ground was firm and somewhat elevated), having been selected as the starting point of the first spur, a strong moonj rope, 1,250 feet long, and 10 inches in circumference, was stretched into the river, on poles, along the line AC; the end C being secured to a heavy crib anchor, 10′ × 10′ × 10′; and the end A, which stretched as far as D, 250 feet inland, was firmly fastened to a beam of deodar wood, about 14′ × 8′ × 8′, buried horizontally in the ground at a depth of 5 feet, and placed at right angles to the direction of the rope.

The poles on which the rope was stretched, were driven from 4 to 6 feet deep into the bed of the river, and were from 10 to 20 feet apart. The rope was fastened to the heads of these poles, and was further secured in its position by anchors, each 6′ × 6′ × 6′ placed at every 20 feet; and when it was thus firmly secured in its position, trees were fastened to it at short intervals, with moonj ropes passing through holes made in their butts. Large trees were placed where the stream was deep and rapid, and small ones near the bank, where the water was shallow.

After the spur was thus got in position, numbers of other trees were fastened to the *main* rope, so closely together, as to form a dense line of considerable substance, which had the appearance shown in the rough sketches. In the plate A, A, &c., represent anchors; the firm arrow lines show current of river before the spur was constructed: dotted arrow lines, after the spur was put up.

After the above spur was completed, a second spur 600 feet long was constructed at BE, in exactly the same manner as the first, to check the course of the river above, and thereby help the lower spur. The ends of the main cables of these spurs, near their starting points, were thoroughly secured, so as to prevent their being turned by the river.

When these spurs were started, the river flowed immediately below the right bank; but as the spurs were pushed into the river, and lengthened from time to time, the current below them gradually ceased, depositing large quantities of silt, and forming shoals, which afterwards turned into large sand-banks, and the final result is, that the river has been completely turned in its course. These spurs affected the river not only below them, but also for a long distance above.

The above spurs, after having been put up, required constant repairs and attention. Every flood that came down the river, turned and twisted their ends which projected into the river, and caused gaps in them in certain places, which were repaired immediately after the flood went down a little; and the whole of the spurs restored to their original state in about a week after every flood, so as to resist the river more effectually in the next floods.

The river has been checked in its course in this way since April 1865, and the right bank, which was threatened in 1864, has now been completely protected. Also, the land, upward of 300 acres in area, which was encroached upon by the river during the last 12 years, has been reclaimed and rendered fit for cultivation again.

228. Spurs of the above description, cost about Rs. 3 per foot run at Lahore, and answer best for large rivers. But on small nullahs and petty streams, the same result can be obtained much more cheaply by putting up spurs made of stakes and broken bricks.

In 1865, a small branch of the Ravee, which flows to the north of Lahore, about a quarter of a mile from the city, set towards its right bank above the pucka bridge on the Grand Trunk road, and threatened to breach the road behind the right abutment of the bridge.

To stop this tendency of the stream, and to protect its right bank and the road from the action of the current, three spurs, each about 50 feet in length, were put up at A, B, and C, on the right bank, projecting into the river at an angle of about 45° with the current, and constructed in the following manner .—

Strong stakes 8 to 14 feet long, were first driven (from 4 to 6 feet deep in the bed of the stream) in a row as close as possible, round the place selected for each spur. The stakes after having been thus driven, were fastened and secured to each other, with strong moonj ropes and fascines; and then the space enclosed, was filled up with broken bricks and masses of old pucka masonry, and the work was complete. The bank above the right abutment, was also protected in the same way, with a row of stakes of about the same length as for the spurs, driven from 4 to 6 feet deep into the bed of the river, and broken bricks filled in the space behind them. The bank of the nullah between the spurs, was also sloped back, and the foot of the slope protected with a row of stakes, driven flush with the bed, and their heads secured together, with ropes and fascines.

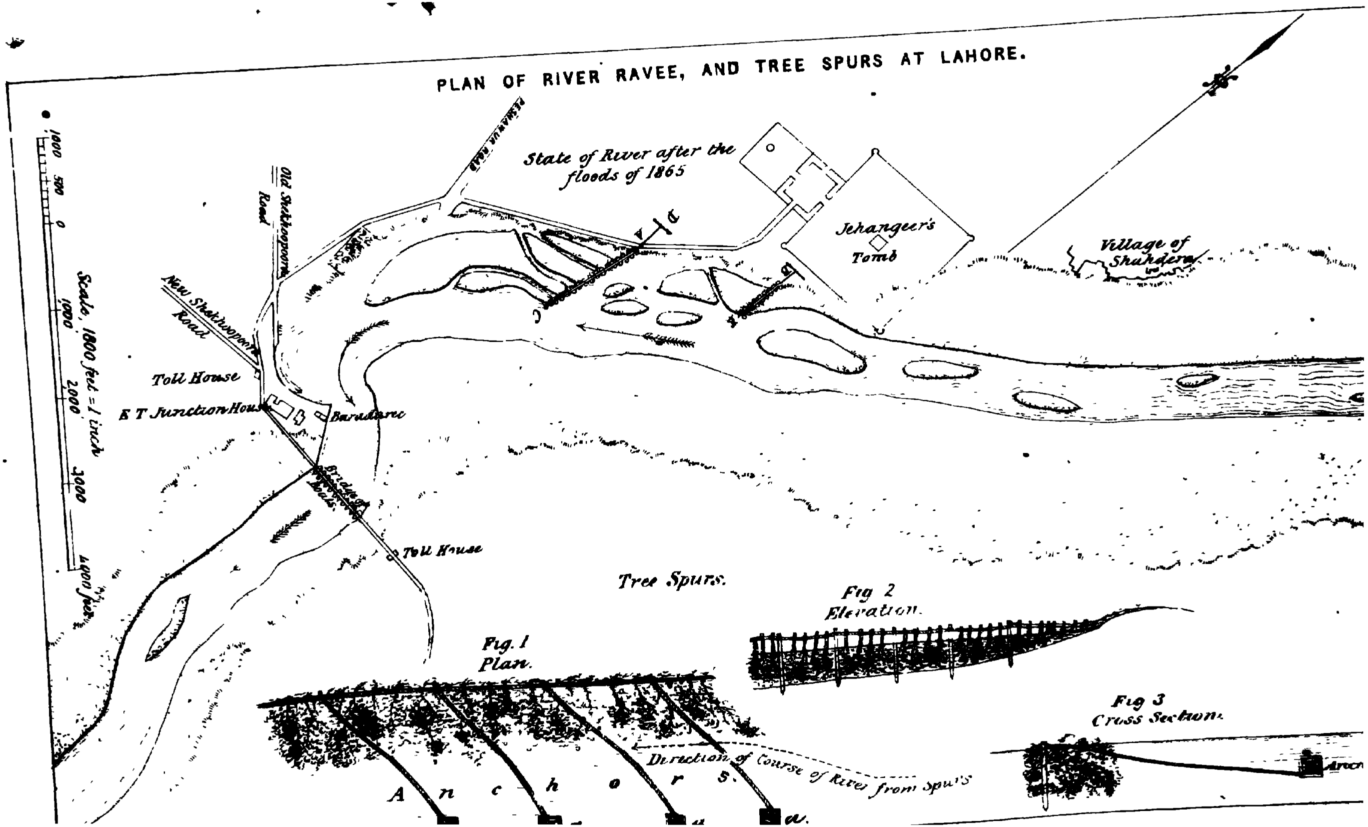
The result of all this was, the *complete silting up* of the stream *between the spurs* and the formation of a new bank, shown by the dotted line *a, b, c, d*. The old bank was protected, the road saved from being breached through it, and the nullah straightened and confined to a channel, the water in which flowed *straight* on to the pucka bridge.

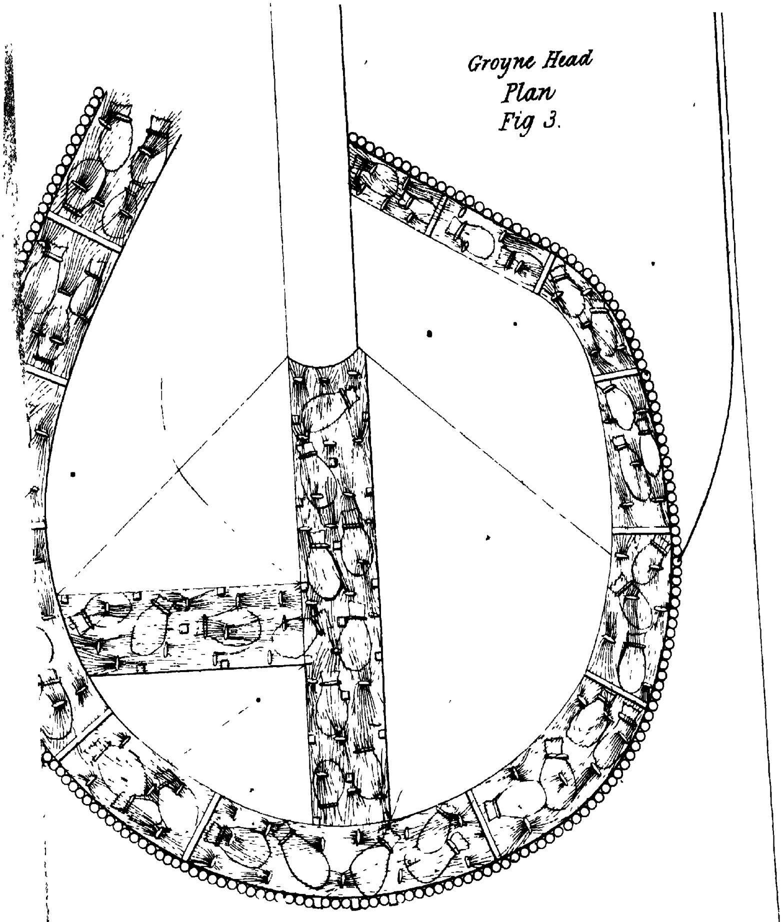
Similar spurs were tried at one or two other places on the same nullah, and proved most effective in protecting the bank below them.

These latter spurs cost Rs. 2 per foot, but wherever old bullees and broken bricks or masses of old pucka masonry can be obtained cheap, the cost can be very much reduced.

229. In the next plate is shown the mode employed on the Gunduck river in Bengal, for protecting the banks of a stream; it is much

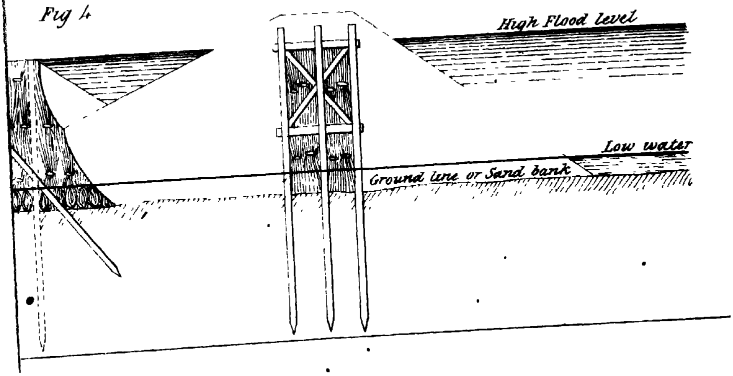
PLAN OF RIVER RAVEE, AND TREE SPURS AT LAHORE.





Groyne Head
Plan
Fig 3.

Cross Section.
Fig 4



in use in Italy and Southern India, and was first brought into use on the Gunduck by Col. O'Connell of the Royal (Madras) Engineers. It consists of a screen or frame of mats, stiffened with bamboos and firmly lashed to a line of piles, which are driven into the toe of the river slope of the bank. These piles are driven in obliquely so as to form a lattice work and make an open fork at top, where they cross each other and are nailed together. Brushwood is thrown in behind this screen loosely. Thus there can be no erosion on the slope of the bank, as the water cannot flow through the screen, and remains quite still behind it.

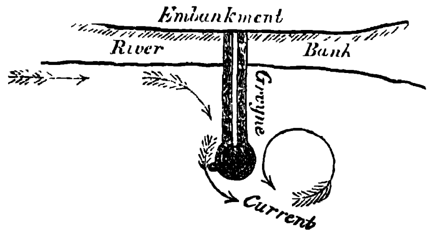
But the current, on being opposed and turned by the screen work, rushes along the face of it with increased velocity, and cuts away the ground into which the piles, which support it are driven; and to pervent it being undermined and overturned, its upper edge is connected with the bank by long heavy palm trees, whose roots are embedded in the bank, and whose tops pass through and rest on the open forks in the row of piles described above. In this manner, the frame of screen work is bound by the head to the bank, and prevented from falling over if undermined, or falling back from the thrust of the current.

But it still remains to prevent the screen work, when undermined, from letting the current in under it, and causing it to float up to the surface. This is done by forming a platform over the palm trees stretched out from the bank, and weighting this platform with earth or sand bags, so that when the sand is removed from beneath the screen, the weight above continually keeps the piles pressed into the sand. In *Plate* XXXV., *Fig.* 1, the dotted lines show a screen, which has subsided 12 feet from its initial position, pressed down by the weight above, as the supporting material was withdrawn from below. "Snakes," formed of straw-ropes platted into a mat filled with clay and made of a cylindrical form are used to protect the foot of the screen work outside from excessive erosion.

The whole of this protective structure costs not over Rs. 2-4 per foot run. It has been found a most efficient protection to banks, exposed to severe eddies, but its use should be limited to the protection of the river banks, as when applied to the defence of groynes projecting into the stream, it is easily overthrown.

230. The next construction, and the most important of all, used in these training works, is the Groyne. This groyne is run out, at right

angles to the direction of the main current, along low sand banks, and across small channels where it is desired permanently to turn the course of the stream. They are simply earthen bunds, except their heads; the earth being well rammed and turfed with long grass to break the roll of the waves on the slopes; and in places where the bund crosses hollows or channels, the toe of the slopes are piled. When a stream is opposed at right angles by a groyne, the head of the groyne becomes the new bank of the stream and the current bends out towards that point for some distance up-stream, and in the angle formed by the junction of the bank and groyne, the water is almost still. From this it will be evident that the erosion of the stream on such a groyne is chiefly confined to its head and a certain distance inwards from it, which distance depends on the angle the line of the groyne bears to the direction of the up-stream current; if it is less than a right angle, the distance effected will be less, but there will be *more* strain on the head; if it is more than a right angle, the distance exposed to abrasion will increase, until at about 130°, the stream will run along the entire length of the groyne and its whole length will require to be protected.



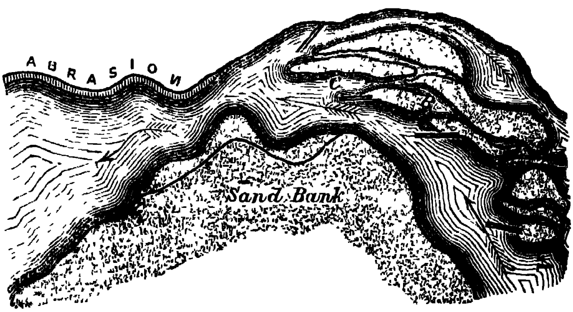
It is found that bunds formed of sand and turfed are quite strong enough for groynes with good heads, as there is but little pressure on them from heaping up the water on the upper side. The difference of level is seldom over 6 or 8 inches. The section used was 4 feet crest, and 2 to 1 slopes, and it was quite sufficient.

231. The head is the difficult part in a groyne. It is probable that the bed of the river may be cut 20 feet in a few days, which would undermine any pile that could be driven into it; so that piles, although used, cannot be depended on by themselves for this purpose. They are now used in order to keep the whole structure of the head together, and brace it both vertically and horizontally. *Fig.* 3, in *Plate* XXXV., is a plan of one form of head used successfully. It is composed of two rings of bamboo piling 15 feet apart, driven in a circular form round

the toe of the slope of the groyne bund at its head. Inside these rows of piles is packed brushwood fascines in layers about 2½ feet thick, weighted down with sand bags. The bund is then thrown up inside this brushwood fence, and well rammed and consolidated, and by its weight serves to keep the brushwood round it pressed downwards and outwards, so that when it is undermined, as it is sure to be, the whole sinks down in one mass and is built up again in the same manner. Of course, the head spreads out on all sides as it subsides, but that only gives it a firmer foundation, and, as in filling in from the top a slope is formed, the more the head sinks into the river the stronger it becomes. Care must be taken to prevent a chasm occurring when the head falls out, between it and the groyne bund. One of these heads was put in last year to protect a groyne which had been broken, there being at the time 31 feet of water immediately under the spot, and it withstood, during the length of the rains, the whole force of the river.

The small Nose shown on the groyne head in *Plate* XXXV., *Fig.* 3, is a contrivance for throwing the scour which takes place under the toe of the bund and round the head, further out, and where it is used, it prevents abrasion inside itself, and accumulates the force of the current on its own head. As long as it can be held it is of use.

232. Light cold-weather spurs are constructed of two rows of bamboo piles 4 feet apart, and filled in with brushwood fascines weighted down with sand bags. They are not calculated to withstand the force of a current, but are useful in training it at low water, and are erected on the tail end of shoals to encourage their extension. An example of this kind of work, constructed lately on the Gunduck is given in the sketch, A, B, C. This river has a volume of about 270,000 cubic feet per second, with a velocity sometimes of over 7 miles per hour. The rise



from summer to flood surface is 14 feet, and depth of stream at low water 10 to 12 feet, so that in flood the current is 26 feet deep.

233. *Plate* XXXVI., is a survey of the Ramdowlee reach, in the Gunduck River, in December 1869. It will be seen that, in the preceding season, the stream ran along the left bank in the channel B, B ; being driven across from the right bank by a point composed of kunkur clay at Thahara. In 1868, a breach had been made at Ramdowlee, and a deep wide channel scoured through the river banks and bund ; and there is no doubt that, but for the protective works of 1869, the whole line of embankment from Rewah Tollah to Ramdowlee would have been carried away. The first thing done was to erect three strong lines of bunds across the breach line and to push forward the bank of the river to its original position of the year before, raising it to its normal height, and protecting with a line of the construction called "screen work," *e, e*, already described. A low water brushwood spur *d, d*, was thrown out just above the screen work to break the force of the current against it. Higher up another brushwood spur, *c, c*, was placed, to catch any eddies caused by the agitation and rush of water at the spur bund or groyne, *b, b* ; and a little above this groyne, was a small spur, *a, a*, which it was found necessary to erect in order to prevent the current from cutting into the rear of the groyne, which it threatened to do at one time.

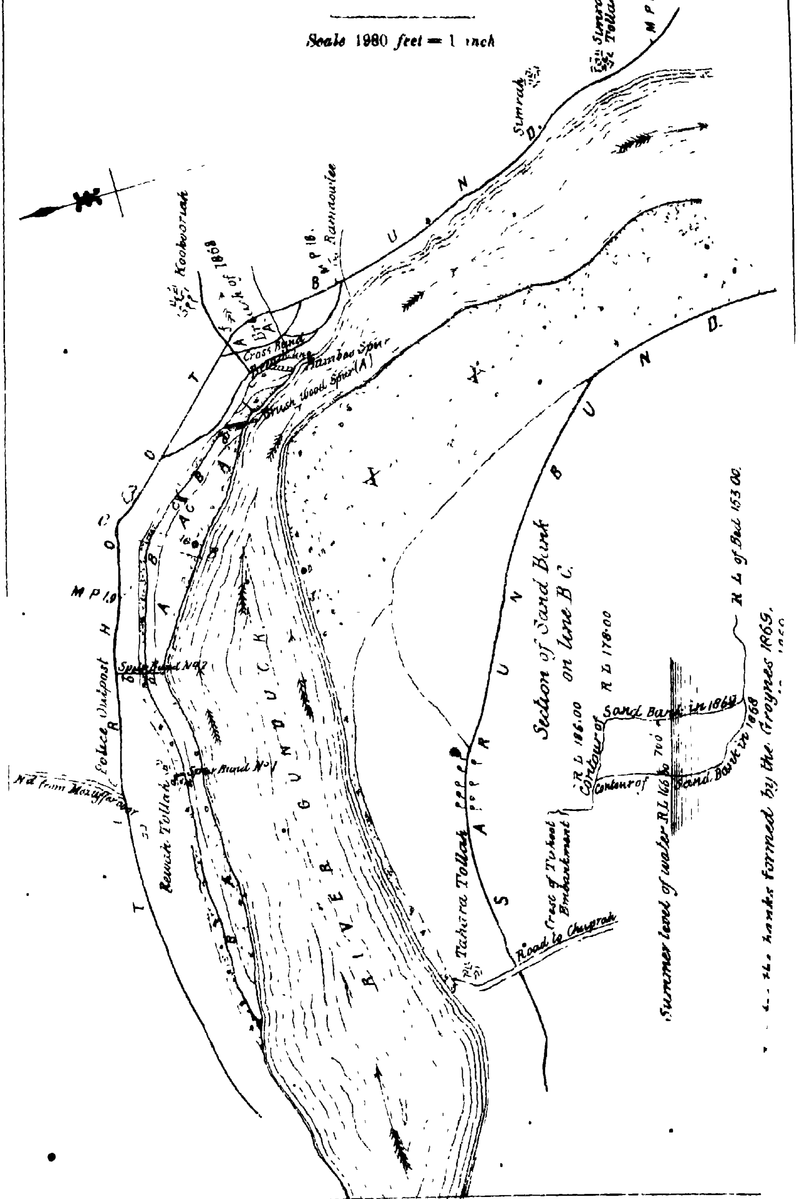
The groyne *b, b*, was the most difficult and important work of this system. It was thrown across a deep channel and along a submerged sand bank, and was composed entirely of sand, turfed with sods. It was the first work of the kind tried in this river, and its head was carried away four several times during the freshes. After great trouble and many different attempts to protect it, by sinking boats, screen work, and "snakes," it was, at last, thoroughly and effectively protected by a brushwood head, similar to that already described as a "groyne head." The water which was heaped up by this groyne rushed round its head with great velocity and scoured out a hole of over 40 feet in depth. This was filled in by constant layers of brushwood fascines and bags, which formed for themselves a natural slope. The price of head work may be estimated at Rs. 8 per 100 cubic feet, including sand bags, binding and sinking, and bamboo piling. This groyne caused to be formed the bank A, A, A, above and below it, the height of which, it will be seen by the section, is 25 feet, bringing its top to a level with the bank of the river. This sand bank extended down to the shore of the breach and caused its mouth to choke up. The groyne should have been made longer had the season admitted, so as to drive the current across the river and on to the shoal marked *x, x*, on the right bank. This has since been done.

234. *Plate* XXXVII, is a survey of the Lallgung Reach of the Gunduck. In the form of the channel and the position of the point threatened, it is very similar to that at Ramdowlee. A high kunkur formation on the right bank leads the stream directed against the Saltpetre Factory at Jahanabad. B, B, shows where the main stream ran in 1868. The water in high freshes spread over the Deearah, *y, y* ; and in its endeavor to discharge itself through the narrow channel, opposite the Saltpetre Factory ; rushed with great force round that point and scoured out the ground immediately under the slope of the bund to a great depth. A spur bund was thrown across the low land of the Deearah, made entirely of sand, and a head was made to it, which although carried away three times, was at length re-built in the way done at Ramdowlee. This groyne, it will be seen, has produced a great effect on the direction of the stream,

SKETCH OF THE RAMDOWLEE REACH—RIVER GUNDUCK.

Showing the effect of groynes placed in the Stream to divert the Current.

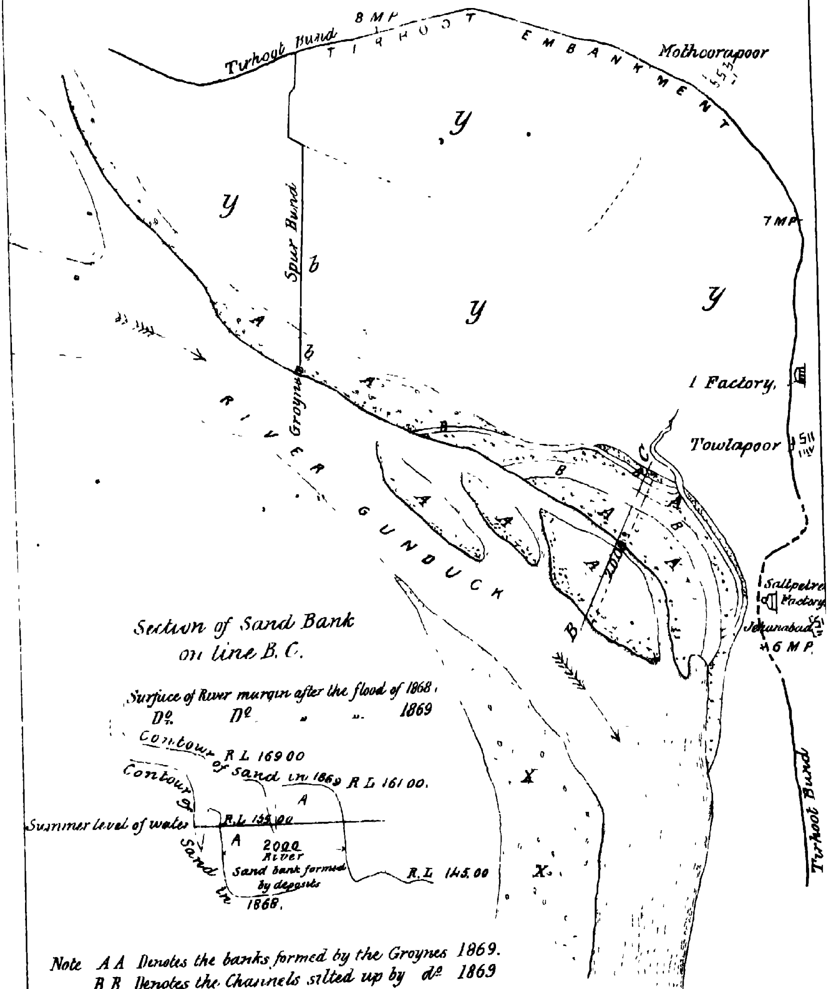
Scale 1980 feet = 1 inch



SKETCH OF THE LALLGANG REACH—RIVER GUNDUCK.

Showing the effect of Groynes placed in the Stream to divert the Current.

Scale 1980 feet = 1 inch



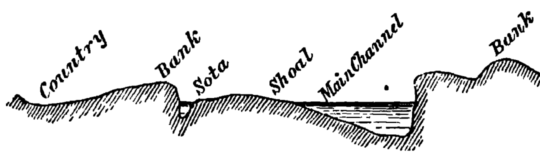
Note AA Denotes the banks formed by the Groynes 1869.
BB Denotes the Channels silted up by do. 1869

causing it to cut away the shoal *x*, *x*, on the right bank, and to deposit larger sand banks A, A, A, at the threatened point. The width of this sand bank near the factory is 2,000 feet, and its height (*see* section) is 16 feet.

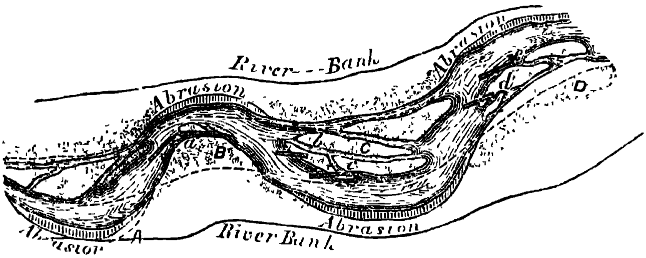
235. It is a mistake to suppose that intermittent attempts at controlling rivers of this description are sufficient. Works of this nature should be permanent, if the protection is to be permanent. No extent of shoals or sand banks can be depended on for one season, as a protection. A mile in length and half a mile in breadth can be melted and carried off in two days if the river set on it. It is, therefore, necessary to have them repaired, extended, or modified every season; there is no such thing as turning a river of this sort once for all, and then leaving it safe.

Cold-weather training works are also continually necessary, because at that season, the high water groynes, &c., are high and dry, and do not control the stream at all; and it has happened that all the benefit accruing from their action has been destroyed by the stream in the low season, which, being a small volume and of greater velocity than the freshes, runs in and out among the high water spurs without being in the least controlled by them, doing great mischief. Low-water brushwood spurs, as already described, are used for this purpose: they cost from Rs. 2 to 2-8 per foot run, driven and filled with brushwood. This description of work is of great value in training a large stream, as it is found that the direction which the main stream takes in the cold season will be almost exactly the same as that which, if let uncontrolled, it will generally keep during the floods.

236. But, for cold weather spurs to have much effect, they should be commenced two or even three reaches above the point to be protected. These deltaic rivers (as is well known), whose large silt laden volumes flow with small velocities, in wide beds filled with sand, are always serpentine in their channels. Their streams are continually engaged, while forming a shoal above on one side, in moving away another shoal below on the other side: and, having carried it a short distance down the channel, depositing it again in another shoal; so that there is always one shelv-



ing and one steep bank, the former silting and advancing, the latter abrading and receding. The section shows the normal section of a deltaic river channel. The cutting, except where some obstacle restrains and checks the stream, such as a sunken boat or a spur head, is almost



always done by the edge of the current and not by the bottom of it and thus the greatest alteration in direction of the channel takes place when the river is falling or rising, and low, and not when it is full. It appears desirable from the experience gained in these works, that all training or protective work should be placed on the shelving bank, as shown in this sketch. This is not so difficult to do as may appear at first. The silting and the abrading banks are always alternate and reciprocal, as in this sketch. Suppose A is the point to be protected; instead of placing a work at or near A, it would require one of a slighter construction, and be more efficient at *c*, its reciprocal silting bank, by which the point above it would be removed, and the channel take the direction of the dotted lines. The higher up this system was continued from the threatened point, the better; and, indeed, there is no doubt, to train a river effectually and easily, not isolated spots, but its whole course should be controlled.

237. Mr. Leonard, C.E., in his report on the Training of the Hooghly, mentions a brushwood spur used on the Vistula and Danube, in Austria, with great success. It is composed of rafts of brushwood made of fascines, strongly lashed together, about 3 feet in thickness, and 20 to 30 feet long by 10 to 15 broad, the centre of which was filled in with stone, good clay, or sand bags, and the rafts were then sunk on the site of the spur one over another, until the spur reached the water level. This is nearly the same method used in the Gunduck, and is much cheaper than

any other that has been tried, and the only protection that is known that can be depended on to last through the season.

238. Where stone is available at a cheap rate it is generally the best material for these works, especially when the depth of piling is great, as timber piles of any length are often very dear. The following practical hints on such works will be found useful:—

For works in depths of over 2½ fathoms, use the largest stone available; small stone, used merely to fill up the interstices between large ones, being useless—wasted in fact. The base of the spur may be laid out a few feet more than double the height; the stones will stand well at slopes of 1 to 1, and there is no necessity for more than a few feet in width at top. In depths of from one up to two and a half fathoms use ordinary guide and sheet-piling, like the sides of a common coffer-dam, with a line of brushwood about 6 feet wide and 2 feet deep, sunk on either side, to prevent washing about the feet of the piles. In depths of less than one fathom, two rows of jungle-wood piles, driven at distances of about 3 feet apart each way, the space between filled in with brushwood secured down with clay, or stones, &c.

As the depth of water in which the large spurs must be built is often considerable, it will be necessary to adopt every available means which may be likely to economize material; the following plan has often been found to effect a great saving. The spur should at first be laid out only large enough to allow of its being carried up to the level of low water; as it will generally be found that, when the stone-work is carried up to this level, a shoal will be formed on one side, or perhaps, on both sides of it. When the shoal is completely formed to the level of the spur, a line can be set out on the shoal and old spur, of dimensions sufficient to allow of its being carried up to half-tide level. Half-tide level will generally be found high enough to carry the stone-work; but if, when the shoal forms up to this level, more will be found necessary, another can be laid to be carried up to ordinary high-water. By proceeding in this way, a great saving may be effected if the scheme be successful; while, if it fail, that is, if silt do not accumulate as the work proceeds, the worst that can happen is, that the spur must be carried up as it would have been if the attempt had not been made.

When building in currents, the site of the spur should be covered *completely over* with about a foot deep of small stones, or very coarse

gravel, before any part of the work be carried up more than a few feet in height. This precaution is necessary whatever kind of spur be used: if it is not attended to, the current, which always runs round the spur-head, will deepen the site of it as the work proceeds, so that a work which was intended to have been in 10 feet of water may be really carried out in 20. The deepening goes on gradually and almost imperceptibly: but the loss of material caused by it is often very great. In the case of small pile and brushwood spurs, the piles may be all driven first, and then a thin layer of brushwood put over the bottom, before any part of the body be raised.

239. *Floating break-waters*, consisting of an arrangement of logs made more buoyant if necessary, with casks, are also recommended for deepening the channel of a river, protecting a shore from inundation, or removing a sand bank. If these floating logs are moored on the edges of the navigable channel, athwart the stream, the current would be thrown more into the bed or middle of the river (from the corner where the logs are supposed to be fixed), till it is opposed by the next log fixed at the next corner; whence, again, a new and improved direction of the current may be given; by thus working at the different corners where the stream has a set on the shore, and is tending to increase the elbow already formed—and remembering always, that the angle of incidence is equal the angle of reflection, which will determine the inclination of the logs, a considerable effect may be gradually produced by the bulk of the water being impelled into the middle of the channel.

If the connected logs, are, instead of being placed athwart the stream, so situated as to keep back the water contained in its channel, and are kept at command by having chains at one end secured to the bank, and at the other end so fixed as to maintain the logs directly across the current, and if this be done on both sides of the river, there will be a rush of water between the ends most distant from the banks, which will constantly act in deepening the passage in the middle, and generally along the bottom. Wherever shallows occur, this method would be applicable.

In this way floating spurs can be fixed, being movable as on a pivot at their shore ends. These logs should always be movable, so that their inclinations may be altered as the set of the stream gradually changes,

and that they can be removed during flood time. Their depths and breadths must be proportioned to the power of the river.

240. 2. To *prevent* Inundations, either the *set* of the river must be altered, or Embanking must be resorted to, or a free'er outlet must be afforded to the flooding waters in their course down-stream. To effect the *first*, the means already described may be resorted to, the attempts being continued with perseverance through several successive seasons. The *second* has been already treated of.

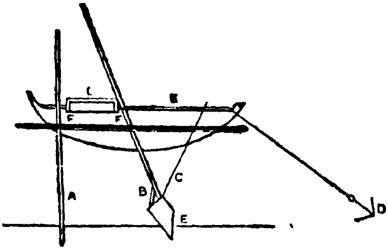
The *third* remedy is often applied by straightening the bends of a river, so as to increase the fall, and, therefore, the velocity of the stream, but the system is now generally condemned, unless it can be carried out down the whole course of a river. For the effect of straightening any particular bend by a *cut-off*, is simply to save the land above at the expense of that below, the flood waters being thrown into the river below the cut-off more quickly than they can be passed on, while nature revenges itself in the end by caving out the banks until the velocity of the stream and resistance of the banks are again equalized, or perhaps, by establishing another bend. The greatest benefit to be given in this direction would be by confining the exit of the water to one channel through the delta, whereby the depth of water would be increased, bars at the mouth swept away, and the flood waters above passed off. Of course, such an operation on the delta would involve great expense and much Engineering skill, but both money and skill would be expended in the right direction.*

241. 3. The most common *Obstacles to Navigation* in Indian Rivers are rocks—kunker banks—sunken trees—and sand or mud banks. The last are best removed by diverting the current of the river against them by means of spurs as above described. Dredging may also be resorted to in particular cases, but it is generally very expensive and attacks the effect and not the cause of the shoal. The works generally employed for removal of these shoals in Indian Rivers are called *bandels*, and are similar to the screens already described.

242. The following simple dredge has been proposed for opening a channel through shoals when bandels have already been constructed.

* The Amazon, which discharges its waters by a single mouth, carries them 150 miles into the sea, and effectually prevents the formation of any bar. The mouths of a delta river carry on the silt a short distance at a feeble rate, when it is met by the tide and thrown up in the shape of bars.

A—Pile for keeping boat steady.



B—Scoop.

C—Rope for raising scoop.

D—Anchor.

E—Platform on which to throw the stuff.

FF—Beams tying sides of boat.

G—Platform for men to work the scoops.

Raking up the sand, by drawing a "furrow" through it to be carried off by the stream, has been tried, but found not to answer. This would be very effective in clay, or clay and sand, but in sand alone, lying for some distance along a shallow channel, its action would be very limited.

243. Sunken trees are generally removed by blasting, and the following account of work of this kind as actually carried out on the Gogra river, in Oudh, by the late Lieut. Carroll, R.E., will give all needful details, and be found useful by those undertaking similar work.

It is necessary, in the first place, to describe the general features which produce the difficulty of removing a sunken tree. The current of the Gogra flows in many places $2\frac{1}{2}$ miles an hour, or 3·6 feet a second. This speed is quite common round the edges of a kunkur rock, or between the branches of a sunken tree; in many such places it is much higher than this, and as the pressure of the current is proportional to the square of the velocity, the difficulty of working boats, or placing charges of gunpowder may be considered to increase in the same ratio. The trees are found sometimes wholly, sometimes partially, immersed in the channel, or they are found partly or wholly buried in the sands, and only creating danger in the rains, when the floods rise over their branches and hide them; or they are found thrown up on the sands and not imbedded, or lying fallen on the banks ready to be swept in at the next floods; but wherever they are found, they offer a very indifferent mark for the action of gunpowder. The roundness of the branches and their small surface compared with their strength, the toughness of the roots, and the massiveness of the stem, combine to make the removal of a large tree a tedious and difficult matter.

244. The means at first employed for the blasting of trees in the absence of better ones, where charges of from 25 to 50 lbs. of gunpowder, contained in tin cylinders, and fired by means of tin tubes rammed with fuze composition, and attached to the cylinders by a water-proof joint. The cylinders were provided with loops of iron-wire projecting from the side, by means of which they could be lowered into the selected spot, by sliding them down bamboos, previously driven in and stayed against the branches of the tree. This method of placing the charge has been retained, as it is found that no moderate weight attached to the cylinders will retain them in their places in a strong current, and because in many places a diver cannot be safely sent down to place the charges; but the mode of firing by fuze tubes was abandoned as soon as possible; it is very inconvenient at any time, and the tubes were liable to break; they were also very uncertain in depths even of 6 feet, and they could not be employed at all in considerable depths.

245. Another method of firing charges employed has been found very effective and,—granted that the cylinder and tube have been properly tested,—it is perhaps the most certain of all. Instead of the thin tin tubes above described, a tube of about three-fourth inch diameter is employed, and soldered into the cylinder near one edge. A thin bamboo lashed to the cylinder and tube secures the latter from being injured, and the cylinder and tube thus prepared and tested can be stored in the magazines ready for use. The testing is done simply by filling the cylinder with water, through the tube, till the latter is full to the top. If the cylinder will stand the pressure of a 10 feet head of water thus applied without leakage, it will bear to be immersed (when filled with the charge) to a depth of 15 feet, or if very tightly filled, to a depth of 20 feet. The charges thus prepared may be placed, as before described, by sliding them down on bamboos into the chosen spot.

The firing is effected in the following way, which is believed to be novel. Into the top of the tube, which projects above water, is fixed a fuze which is rammed in a tin tube 9 inches long and of a slightly conical shape. The composition of the fuze contains near its head a pellet of iron of about half the diameter of the lower end of the tube. The burning of the fuze makes the pellet red-hot; it is prevented from blowing out upwards by two cross wires, and consequently when the

fuze has burnt out, the pellet drops through the tube, and ignites the gunpowder. A large number of charges have been fired in this way, and no failure has ever occurred through the pellet's not falling or not being hot enough. Charges thus prepared have been used in from 15 to 20 feet of water, and it is manifest that with flexible tubing, such as block tin gas-pipe, that they might be employed in much greater depths and with some advantage where time did not admit of the construction of a galvanic battery. The fuzes should be rammed with ordinary fuze composition, which is a mixture of—

	lbs.	oz.
Saltpetre,	3	4
Sulphur,	1	0
Mealed powder,	2	12

and care should be taken that the pellet is always considerably smaller than the tube it has to fall through, and that it is not angular in shape.

246. The Magnetic Battery has also been employed on the Gogra with success, and though the mode of using it and the construction of the fuzes are amply detailed in Messrs. Wheatstone and Abel's Report on the subject in Volume X. of the Professional Papers, Royal Engineers, part may be repeated here in order to render the account of the rough, but effective fuze here employed more distinct.

The ordinary fuze consists of a wooden plug carrying a gutta-percha core inserted through its axis, and containing two fine copper wires insulated from each other. The core projects three-fourths of an inch from the lower extremity of the plug, and its end is cut off clearly, so as to expose the extremities of the wire, which are one-sixteenth of an inch apart. The upper ends of these, insulated wires are separated from each other, and put into connection with two small copper tubes or eyes, which are fixed crossways in the head of the plug. These eyes are intended for the reception of the main wires of the battery, and the current in passing has to flow by the insulated wires contained in the core of the fuze, and to leap the interval of one-sixtenth of an inch which separates them. To enable it to do this, the exposed ends of the wires are covered with an explosive composition of feeble conducting power, consisting of an intimate mixture of the following ingredients:—

Sub-phosphide of copper,	10	parts.
Sub-sulphide „	45	„
Chlorate of potassa,	15	„

About a grain of this composition is inserted into a small cap of metal

foil which is twisted on the end of the gutta-percha's core; and the bursting charge is contained in a tin tube of a few inches in length, which is fitted on to the end of the fuze plug, and corked at its lower extremity.

When the fuze is about to be used, and has been prepared in the manner described, the end of the wire which leads from the battery is pressed into one of the copper eyes, and another shorter wire is pressed into the other eye, and its upper extremity put into connection with the outer surface of the vessel containing the charge, if it be of metal or with a metal plate attached to it; if it be of wood, the circuit through the fuze and main wire is completed by the water between the surface of the cylinder (or the metal plate), and a metal plate attached by a short wire to one of the poles of the battery, and immersed in the water. The neck of the cylinder through which the fuze has been inserted is of course stopped with a water-tight plug. The charge being thus prepared and placed, the boat containing the magnetic battery is withdrawn to a convenient distance, and the charge is fired by a smart turn of the handle of the battery, which by causing the armatures of the magnets to rotate before their poles, produces the succession of induction current necessary for ignition. The main wire leading from the battery must be carefully insulated from the water, and the connection of the return wires with the water carefully made. The other connections with fuze and battery need not be made with as much care as when working with the galvanic battery, for, here we have to deal with electricity of higher tension than is produced by any galvanic battery of moderate power.

247. This description of the fuze and its use, all of which may be found in greater detail in Messrs. Wheatstone and Abel's Report, above referred to, renders it easy to describe the rough but effective fuze, on the Gogra, employed in a few words. In place of the wooden plug, a cork is employed, which does the double duty of holding the gutta-percha core and of corking the cylinder. The core itself, instead of the carefully manufactured article above described, may be simply made by taking two pieces, each a few inches long, of single insulated copper wire cut from the coil employed as main wire, cleaning them for about half their length, and fuzing them together by passing a hot iron over the gutta-percha with which they are covered. They are then pressed together till the end of the wires are one-sixteenth of an inch apart. A shorter interval may

be employed with advantage, say one-twenty-fifth of an inch. This core is passed through the cork, and the portion of the fuze wires which have been cleaned and exposed, project above it for the purpose of making connections. One of these, supposing the fuze to be primed and placed in the cylinder, is bent over and put into connection with the metal of the cylinder generally by folding it up with a little slip of tin projecting from the neck; the other is put in connection with the main wire of the battery.

The priming of the fuze is previously effected by cleaning the inner end of the core, wrapping a small paper cartridge round it, inserting a grain of the magnet fuze composition and filling the rest of the cartridge with mealed powder slightly rammed, to prevent it and the fuze composition from separating from the end of the wires. The end of the cartridge may be plugged with wax. This small cartridge is quite sufficient as a bursting charge for 50 lb. charges; but for larger charges a larger one would be preferable, and could be tied round the cork, which would then be passed altogether into the charge, and other arrangements made for corking the cylinder.

248. A water-proof substance must always be employed to cover the top of the cork, and protect the connection of the main wire with the fuze which is just outside it, from the water. The substance here employed is that called Kitt's composition; it consists of a mixture of the following ingredients, slowly heated together:—

				lbs	oz.
Resin,	...	...	...	7	8
Pitch,	...	...	...	6	14
Bees' wax,	...	...	...	6	14
Tallow,	...	...	...	1	14

In warm weather it should be kept cool in water, or it becomes too soft to use with convenience; in other respects it is perhaps the best and most flexible water-proofing that can be employed—an important point where any fuze or wire leading from the cylinder is liable to flexure or vibration.

249. The only precautions that are necessary to be taken with these fuzes, beyond the perfect insulation of the main wire from the water, are that its connection, which is just outside the cork, should be kept out of contact with the surface of the cylinder, and that the cylinder itself should not be washed over with any water-proofing which would

insulate it from the water and check the return current. The main wire should also be tied to the cylinder, so as to prevent any strain coming on the fuze or its connections.

The percentage of failures with these fuzes has been exceedingly small. Out of 60 charges lately fired in depths of from 8 to 20 feet of water, and varying in amount from 50 to 450 lbs., there have been only two failures, and these were due probably to defective insulation of the main wire and not to the fuze.

250. The Magnetic Battery and insulated wire were obtained from the Telegraph Department; the latter is copper of about one-eighteenth inch diameter, coated with gutta-percha. The battery is contained in a box about 14 inches square, and 9 inches high. Its great advantages over the Galvanic battery are, that it requires the use of no liquid; it is always ready for use; its power is constant; and it is more compact and less liable to injury. The magnet fuze composition was prepared at Calcutta, but as it may sometimes be impossible to procure it, it is important to know a substitute. Mealed powder* when moistened to a certain extent is an excellent one. The mode of preparing it is described in the Royal Engineers' Professional Papers before referred to, but may be repeated here. Dissolve chloride of calcium in alcohol till the solution is saturated; steep mealed powder in it till it has thoroughly imbibed the alcohol and with it the chloride of calcium. Dry the mealed powder completely, and preserve it so in a closely stoppered bottle. When required for use, a few minutes exposure to the air will, by absorption, render the powder sufficiently moist for use; this may be known by its showing a tendency to collect together into small granules. It may then be used in precisely the same manner as the sulphide of copper composition. Twelve or fourteen trial fuzes have been fired with this composition in succession without failure, but it has not yet been employed in place of the magnet fuze composition; the trial was considered to prove that it was sufficiently certain for ordinary use. Mealed powder may also be moistened to the proper degree for priming fuzes by simply folding a small quantity in thin cloth, and breathing through it. It is apt, however, to dry too soon, and it is not by any means certain of ignition. Nothing further need be said on the subject of *firing* charges, but it may be added that the charges in common use are 25 and 50 lb. ones,

* Could not be depended on during the hot winds or very dry weather.—W. J. C.

contained in tin cylinders. For use in depths of 15 feet and less, these cylinders require no strengthening, but for greater depths they should be strengthened with either stays or rings.

251. It will render this account more complete, to give a few instances of the demolition of trees, out of the number that have been removed on this river.

In December, a large semul tree, lying 200 feet from the banks at a village called Chupree, was removed by blasting. The depth of water at the root, which lay upstream was 20 feet, and the current 2½ miles per hour. A number of separate branches spread out under and above water, and were demolished by separate charges of 25 to 50 lbs. of powder The root and stem gave most difficulty; the latter was however broken by two successive charges and separated and dragged to shore by crab-capstans. The root which spread out in irregular masses to a diameter of 20 feet facing the current, resisted a great number of charges, and several cylinders were broken on its projection, others of the charges broke off portions, but brought other new ones up to the surface. The tree was finally demolished after the expenditure of 850 lbs. of powder. It would have been a manifest saving of time if a 400 lb. charge could have been placed near the root, but the strength of the current, and the shape of the root, rendered it impossible.* The crab-capstans employed were roughly made, but have proved very serviceable. They are a convenient mode of obtaining great power, and a few carpenters and blacksmiths can make up one in a day or two.

In February, a large tree lying near the bank at the village of Tajpoor was removed. The stem was a mass of wood of about 10 feet in diameter, and the same in length. The branches were demolished in the ordinary way, but 50 lb. charges had no effect on the stem. As its upper side projected above the surface of the water, it was ultimately split up by small charges placed in holes bored in the wood. Here also a charge of 300 or 400 lbs., if effective, would have saved time; but neither was there a good position for one, nor do I believe that it would have had any further effect than to throw the stem a short distance to one side or other, as the wood was perfectly sound, and of great strength.

Near the same place a large tree lying half on the bank and half in water was demolished by a 200 lb charge, followed by a few small ones The charge was placed in a cask under a hollow of the tree and in the water; the timber directly over the charge was about 12 feet thick, and embraced a palm tree that had grown with it. The timber around it was completely shattered by the explosion, but the palm itself was unhurt. Here the good effect of the charge was due to the timber being rather decayed, and to the good position in which it was placed.

In February two trees, each 9 or 10 feet in diameter, were removed from the river at the village of Belthfah. The water was too shallow for the use of large charges. On one of them a few 25 to 50 lb. charges were first employed, and the stem was lifted out of the sand, so as partly to project above water; it was then split up by small blasts placed in the wood, and its demolition completed with 25 and 50 lb.

* Large boats could not safely be got into position in front of such a tree, and even if they could, a cask large enough to contain 400 lbs. of powder would offer such a surface to the current as to be quite unmanageable; in some positions a cask may be sunk by another plan, described further on.

charges. The other tree was removed in the same manner, and in both cases the fragments, which were large, were dragged out by three capstans working together, and hauled up the main bank by an English gyn. Attempts made at the same place to remove a sunken banyan tree were unsuccessful. The roots resisted several small charges, and ultimately a charge of 165 lbs, and a force of 10 tons applied by means of capstans and cables, had no effect in tearing them asunder.

In February, a large tree lying on the sands above the water level was demolished by means of two 25 lb charges, fired simultaneously in the following manner — From the main wire of the battery, a branch was led to each charge, and as the cylinders lay in dry sand, whereas a moist connection is necessary to complete the return circuit, the return wires of the fuzes were connected with metal rods driven down into the sand till moisture was reached. To make the connection more perfect, water was poured over each cylinder and the sand round it. The battery was 100 yards away at the edge of the river. The return wire and plate were immersed in the water as usual. Both charges ignited perfectly simultaneously.

In March a large tree lying in dead water, and a strong current at the village of Tickyah, was partially removed. Here also two charges were fired simultaneously, but with little effect; ultimately a charge of 450 lbs was sunk and fired in the following manner —A cask was prepared and tarred, and two rings of hoop-iron were nailed on its ends, so as to project from its sides and allow it to slide down a rod. A bamboo 4 inches in diameter was driven in the best spot available, and the cask was passed on to this by means of the rings, it then stood floating on the water in an upright position and empty, but with the fuzes prepared and inserted. In this case the independent fuzes were employed, as it would have been a difficult matter to recover the cask had one failed. The cask was filled and sunk in its place in a depth of 20 feet, by weights; the bamboo was securely stayed against the tree, and the main wire being connected with one of the fuzes, the boats were drawn away, and the charge fired.* The effect was not so good as might have been expected, some lower branches were separated and the tree was thrown into an upright position, but the stem was quite uninjured. The remaining operations require no notice.

A tree buried in the sand and liable to become dangerous on the shifting of the channel, was attacked in the following manner:—Its position and size were first ascertained with iron sounding rods. The stem was found to be 8 feet under the sand, and 7 feet 9 inches under the water level. A good position being selected, an iron tube 11 feet 6 inches long, and 1 foot in diameter, was driven down beside it to a depth of 11 feet, by means of a *ringing* engine. The tube was then bored out to a depth of 10 feet with a boring tool 10 inches in diameter, and provided with a leather sand valve. A 50 lb. charge was passed down the tube to that depth, and the tube was drawn by a differential pulley hung to the *ringing* engine. The charge was fired by means of a tin tube and pellet fuze but without much effect. It was neither large enough, nor had it been placed deep enough. The tube should have been driven 12 feet deep, and a 100 lb. charge placed at a lower level than the stem. Time did not admit of repeating the operation, but the more dangerous part of the tree was removed by other means.

* In this manner the drag of the current on the cask was rendered harmless, and in spite of it the charge was successfully sunk in to its position under a perfect net-work of branches, in a place where it would have been quite impossible to bring a large boat

In this operation the Ringing engine was worked in the following way.—The rope attached to the ram was passed down, and through a block at the rear of the engine, it was carried a long distance to the rear, attached to a peg and worked alternately by two parties, one of which took it up when the other dropped it, and the ram had fallen. In this manner nearly double the ordinary number of blows were delivered in a minute, and the men were not fatigued to the usual extent; but of course a double working party was necessary.

A large tree, lying in the sands near a village called Gyaspoor, was removed by small blasts fired in holes made by means of a lever drill. This drill, which was made up out in camp, consisted of an iron frame, carrying a wheel 1 foot in diameter and working on a vertical axis. The frame was provided with keys for clamping it on a square iron-rod 5 feet long, and pointed at one end. This rod could be readily hammered into the stem of any tree it was required to bore, and the drill clamped to it could thus be brought to bear in any desired direction—vertical, sloping, or horizontal—the axis of the wheel was pierced to carry a square iron-rod, in the lower end of which the drill bits were fixed. The upper end was pointed, and pressure was applied to it by means of a lever clamped at any required height to the rod driven into the timber. The drill was driven from a 3-feet wheel placed in any convenient position; it was capable of boring 3-inch holes with moderate rapidity.

252. The following account of the removal of kunkur banks is by the same officer:—

The features that these rocks usually present have been already described, and it only remains to state the means that have been employed in attempts to remove them. The first trials were made last year on a small rock of thin kunkur, lying in from 2 to 6 feet of water, and in a strong current. The apparatus employed was a species of small coffer-dam of a portable character, consisting of an outer and inner frame and sheeting, and including between them 2 feet 6 inches thickness of strong clay puddle. The space enclosed was a rectangle of 4 feet 6 inches by 3 feet 6 inches, the object being to dry a space sufficient for a miner to work in, and drive a shaft down through the kunkur, in which a large charge might be placed and fired. The outer sheeting of the dam was supported by four frames, rectangular in shape, and each 10 feet by 3 feet 6 inches high, braced diagonally and made of $3\frac{1}{4}$ inches sál scantlings. These frames when bolted together at the angles formed a square enclosure, within which the sheeting was put down vertically in 6-inch widths. The sheeting was supported at the back by longitudinal pieces parallel to the top and bottom rails of each frame, and $2\frac{1}{4}$ inches within them. These pieces could be put in position after the frames had been bolted together.

The inner framing was constructed in the same manner, only smaller, so as to allow the space between the walls required for puddling. The surface of the rock being very irregular and steep, it was necessary to put down the coffer-dam in the following manner:—Two boats were anchored over the rocks, and the outer frames previously bolted together so as to form a square enclosure, were let down into the water. A few pieces of sheeting were then dropped in at the angles, and wedged when resting on the rock. The position and stability of the frame being thus secured, the remaining sheeting and the inner frame were rapidly put in, and the puddling commenced. The attempt to dry the dam failed; it was found that the substratum was sand, and the water came up through cracks with which the surface of the kunkur was covered; but there is no doubt that this kind of dam could be used occasionally with advantage where the material to be removed is solid rock or kunkur underlain with clay; it is very portable, and could be put down and taken up much more rapidly than a dam supported by any arrangement of jumpers driven into the rock.

253. The next attempt on the same rock was made with boring tools of rough construction. A portion of the kunkur in 4 feet depth of water having been broken up, an attempt was made to bore down, through the substratum, with the object of placing a 50 or 60 lb. charge at a depth of 6 feet, or thereabouts, below the kunkur. This attempt also failed from the fact of the sandy substratum being too fluid to retain any hole.

Trials were next made on a rock 80 feet long by 50 feet in width, and partly above water; the substratum in this case being clay, the boring tools proved quite effective. The operation of placing and firing the charges ultimately took the following shape:—A 2-inch iron-bar was first driven down into the kunkur to a depth of 6 or 7 feet, and drawn into the hole thus formed, a small charge of powder contained in a thin cylinder of tin was inserted to a depth of 6 feet and fired. It was found that this charge by its explosion produced a narrow crater in the kunkur about 6 feet deep, and after clearing the hole with a boring tool about 1 foot in diameter, a 50 lb. charge was readily placed at a depth of 6 feet under the kunkur, whether under or above water. It made little or no difference in the rapidity of the operation whether the kunkur lay under or over water. The hole having been tamped, the charge

was fired with the pellet fuze,* producing a crater of about 18 feet in diameter, and 6 or 7 feet deep. In this manner the rock was rapidly blown away to a depth of 6 feet under-water, the whole operation not lasting more than ten days, and had arrangements been more perfect, this time would have been shortened very much.

254. In the following season, attempts were again made on kunkur underlain with sand, and under 3 feet of water. The following method was now adopted:—Boats were prepared with framing, and planks sufficiently strong to bear a heavy strain; they were anchored over the rock with an interval of a few feet between them, and lashed together by cross-ties. A light triangle was erected on the boat, and from it was first suspended a beam of wood, shod with a heavy cast-iron pile shoe, and slung from a pulley. This was worked up and down like the ram of a ringing engine till the surface of the kunkur was completely broken up over a small space. On the spot thus broken up, an iron-tube 11 feet 6 inches long, and 1 foot in diameter, was now placed, and driven by a ram slung from the triangle, and worked as before described. When driven to a depth of 7 feet, it was bored out, and a charge of 50 lbs. placed at a depth of 6 feet under the kunkur. The tube was then drawn with a differential pulley, and the boats being removed, the charge was fired by means of Bickford's fuze, producing a crater 16 feet in diameter and 5 feet deep. The operation occupied about 8 hours, but it was not repeated because the river was too high at the time to make it of any real advantage except as an experiment.

255. The following calculation by the same Officer refers to the probable cost of such operations:—On an extensive rock surface it would be easy to accommodate three or more working parties,†—we may suppose three, and it is not too much to assume that, with the proper appliances, each party would fire three charges in a day. Eight charges a day would be a fair allowance for the whole three parties, and supposing such charges to be placed at two-lined intervals, or 14 feet apart, the whole number of charges required to break up a surface of 10,000 square yards would be 462, the quantity of gunpowder about 70,000 lbs., and the number of days in which it could be done 58; but

* This was one of the earliest operations, and no galvanic or magnetic battery was at hand.

† Each pair of boats would take up a considerable space in order to keep the moorings clear of each other.

allowing for unavoidable delays and occasional bad weather, it would be well to calculate on the operation lasting three months, which is about the length of the season most favorable for such work.

The cost of the operation may be roughly estimated as follows:—

	RS.
Working parties, including crews of three pairs of boats, 20 men each, at an average rate of wages of Rs. 5, .	300
Three Lallas in charge of boats, at Rs. 15, ...	45
Hire of additional boats for carriage of men and materials to and from shore, ...	100
Total, .	445 monthly.

As experiment has not yet decided how far it would be necessary to assist the action of the charges by dredging away the débris into deep water, the hire of the three boats, at Rs. 30 per month each, will be added to the above —

	RS.
Brought forward, ...	445
Hire of three boats as for dredging at Rs. 30 per month, each,	90
Total, .	535
Total boat hire and labor for three months, . .	1,605

The work would of course require the presence of an Engineer and a European Overseer, whose salaries however will not appear here. The expenditure on materials would be trifling, except that on vessels to contain the charges. This expenditure could be reduced to a minimum by employing either 100 or 200 lb. charges, in either of which cases, the original powder barrels would be placed in the mines, and no expense would be incurred beyond that of making them water-proof.

If 150 lb. charges be employed, as here contemplated, the cost of tin cylinders should be added to that of preparing the barrels, as it would be necessary to employ for each 150 lb. charge, one 100 lb. barrel, and one 50 lb. cylinder.

	RS.
Cost of preparing 462 barrels, at 8 annas each, . .	231
462 tin cylinders, at Rs. 1 each, ...	462
Total, .	693
Making a total expenditure during the progress of the works of . . . . , ...	2,298

256. The first cost of preparations and of a stock would be as follows:—

The boats employed for boring and for placing the charges should belong to Government; but their cost would be a charge only against the

first operations, as the same boats would answer for all subsequent ones, as well as for any of the ordinary works of the season. Allowing two 150-maund boats to each working party, at a cost of Rs. 1 per maund of tonnage, the estimate would be as follows:—

		RS.
Six 150-maund boats, at Rs. 150 each,		900
Decking and strengthening do., at Rs 50,		300
	Total,	1,200
PLANT.		
Six 2 feet diameter boring tools, at Rs. 50,		300
Three triangles, at Rs. 50,		150
Three differential pulleys, at Rs. 100,		300
Three crab winches, at Rs. 100,		300
Miscellaneous,		150
	Total,	1,200
Grand total first cost of boats and plant,		2,400
Grand total cost of labor and materials,		2,298

The above estimate for plant does not include jumpers, hammers, Ringing engines for driving the jumpers,* by which are here meant simply pointed bars of iron, not steeled; blocks and some smaller stores which in this case happen to be in hand at present. Had these to be included, they would increase the estimate by about Rs. 400.

Taking the figures as they stand, and adding 10 per cent. to cover contingencies, and the wear and tear of tools and cordage:—

	RS.
The total first cost of boats and plant will be,	2,640
The total cost of labor, boat-hire and materials,	2,528

These amounts represent the cost of the operation on a sunken rock, as it would be charged against the sum appropriated for works, and it takes no account of the cost of European supervision and of gunpowder, which would not be so; but where the expenditure of gunpowder is so great, its cost, if it entered the estimate, would become by far the largest item. In the foregoing estimate, the cost has been worked out by calculating merely from the extent of the surface of rock to be demolished, and it has been tacitly assumed that the charges

* The jumpers on all the rocks yet tried could be hammered directly down through the kunkur, which of course can be much better done with a Ringing engine than by hand. In the case of block kunkur it would be necessary to work the jumper in the ordinary fashion.

would in every case reduce the kunkur to a safe depth below the surface. This depth may, and has been assumed as 6 feet, but every additional foot that could be obtained would be of value, and be worth a proportionate increase of expenditure. In order to obtain a clear depth of 6 feet in every case, it would, perhaps, be necessary to use larger mines where the kunkur lay nearer the surface, and smaller where it lay deeper. But it is thought that the average taken, namely, 150 lbs. for each mine, is on the safe side of the truth.

257. The difficulty of entirely dispersing the kunkur thrown up by the explosion of a charge, might be partially obviated by using rather larger charges than those proposed, or by dredging, or by both methods. It is a matter for experiment, as no sufficient data for it exist at present; but it is suggested that it would be economical to work only on the deeper part of a reef according to this method; and where coffer-dams could be constructed, to employ them for the removal of all rock within 2 feet 6 inches or 3 feet of the surface, as in such shallow water they would be readily and cheaply constructed. Coffer-dams appear to have been employed on the Ganges river works with a certain degree of success, but at an enormously greater cost than that here estimated; there are also certain objections to their use, which cannot be gone into here, and many of the rocks spoken of have a sandy substratum which would not admit of their employment.

258. 4. The means to be resorted to for obtaining a suitable depth of water for navigation, are all comprised in the above paragraphs. The expensive system termed lock and dam navigation, often used in France, England, and other countries, which consists in dividing the stream into several suitable reaches or pools, by forming dams to keep the water in the pool at a constant head, and by passing from one pool to another by locks at the ends of the dams, could, it is evident, be rarely applicable to Indian streams. Something in this direction might, however be tried on such a stream as the Ravee, where the river is of a manageable size, and the results to be obtained by its navigation are very important. On this subject, the reader may advantageously consult a paper compiled by Lieut. Heywood, R.E., on River Dams in France, published in the Extra Number of the "Professional Papers on Indian Engineering," (First Series,) in April, 1870, which contains very full information on this subject.

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